Summary of Investigations of Electric Insect Traps

Technical Bulletin No. 1498

Agricultural Research Service

UNITED STATES DEPARTMENT OF AGRICULTURE

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By

Truman E. Hienton *(retired) collaborator*
Agricultural Research Service

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FOREWORD

This bulletin was prepared as a result of the following memorandum, dated April 30, 1969.

To: W. M. Carleton, Director, Agricultural Engineering Research Division

From: E. F. Knipling, Director, Entomology Research Division

Subject: Consolidation of results of light trap studies

In recent years there has been continuing interest in the potential application of light traps for insect detection and control. Our two Divisions have conducted considerable cooperative research to develop useful information in this area, and I believe that we have made substantial progress in determining the potential and limitations of light traps for suppressing insect populations. There exist vast amounts of published information in the literature, and in addition, considerable amounts of unpublished work.

There is a real need for someone to consolidate the available information and bring us up to date on what has been done to the present time, and what further research is needed. Dr. Hienton, before retiring, had expressed interest in compiling this information. Dr. Henneberry and Mr. Taylor, Chiefs, respectively, of the Vegetable and Specialty Crops and Fruit Insects Research Branches, have suggested that perhaps arrangements could be made for Dr. Hienton to compile in publishable form the vast amount of information that has accumulated over the years while he served as Chief of the Farm Electrification Research Branch. We believe that such compilation would be a real contribution that would reflect the efforts and progress of scientists of both of our Divisions.

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Summary of Investigations of Electric Insect Traps

By T. E. Hienton, *collaborator, Agricultural Research Service*[1]

EARLY HISTORY OF THE LIGHT TRAP

The attraction of some adult insects to artificial light was observed and recorded by man early in his history. The first such known record is that written by the Greek poet Aeschylus (525-456 B.C.) in his *Fragments* 288 (c. 450 B.C.) "The fate of the moth in the flame" mentioned by Du Chanois (*1959*).[2] Following next were suggestive lines from the Sanskrit, "The moth hovers round the wick and extinguishes the fire," attributed to King Sudraka in 400 A.D. as indicated by Frost (*1952*).

Fires undoubtedly provided the first artificial light to attract and destroy flying insects. Harris (*1821*) indicated that small fires were desirable "as a mode of destroying insects." The use of fires for luring and killing adults of the armyworm *Pseudaletia unipuncta* (Haworth); cutworm (Noctuidae), and codling moth, *Laspeyresia (=Carpocapsa) pomonella* (Linnaeus) was mentioned by Glover (*1865*). Comstock (*1879*) reported that the practice of building large fires at different points through the cottonfields for the purpose of attracting cotton leafworm, *Alabama argillacea* (Hübner); and cotton bollworm, (corn earworm, and tomato fruitworm) *Heliothis zea* (Boddie), moths into the flame was prevalent for many years.

Kerosene-burning lamps and lanterns succeeded fires as insect attractants. An English entomologist, James Petiver, used mobile lights (lanterns) to attract moths as early as 1695 (Wilkinson *1966*). These light sources were most frequently incorporated into a trapping device and this combination became known as a trap lantern. In a number of cases, a lamp or lantern was used inside a room or other sheltered location where attracted moths were trapped and caught by hand (Kirby and Spence *1815-26*).

Clemens (*1859*) commented in his article on instructions for collecting Lepidoptera that the nocturnal Lepidoptera may be taken by the use of light. One method mentioned was that those who lived in towns lighted by gas would be able to secure many specimens around the lamps. Another method was by

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[1] At the time Dr. Hienton retired in April 30, 1968, he was chief, of the then, Farm Electrification Branch, Agricultural Engineering Research Division, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Md.

[2] The year in italics after the author or authors' names is the key to References, p. 118.

making friends with the lamplighter and by supplying him with pill boxes, he might furnish specimens every morning and some of them rarities.

Knaggs (*1866*) reported the invention of "The new American moth trap" by a Mr. Glover[3] which, in the latter's words, "will catch moths all night long without any trouble to the owner." This trap used a kerosene lamp as the attractant inside a box with an entrance of glass sheets opposite the lamp (fig. 1). It was listed by Wilkinson (*1969*) as the first entomological light trap and its early use and later modifications were described in detail by him.

The development of 11 trap-lanterns of widely different designs, 10 of which were patented, occurred in the United States during the period 1864-77. In 1878, the first year this equipment was tried on a large scale, more than 1,000 lanterns were used near Hearne, Tex. to capture moths of the cotton leafworm and the bollworm, Comstock (*1879*).

Riley (*1885*) observed the attraction of cotton insect moths to electric lights around an Atlanta Hotel in 1881 and made this comment: "Beneath these (lamps) the ground was strewn with dead moths and a quart of them would often accumulate during a single night in the glass of the globe surrounding each light." This is the first recorded observation of electric lamps as an insect attractant found by the author. This observation followed closely behind the commercial establishment of the arc lamp in 1877. From these observations, Riley indicated that "electric lights may be the best and probably the calcium lights and gas lights next; but at present these are generally not economically applicable for field use."

A few years later, Riley (*1892*) in describing traps for collecting and preserving insects, made this further comment: "Collecting by the aid of a strong light is a favorite means for moths as well as other insects, and nowadays the electric lights in all large cities furnish the best collecting places."

Experience in collecting insects at an electric lamp stimulated the development, by McNeill (*1889*), of an insect trap to be used with an electric light. The trap consisted of a tin pail or can charged with cyanide, similar to a collecting bottle, to be attached beneath the globe of the electric light (fig. 2). This is the first publication, found by the author, that describes an insect trap designed for use with an electric lamp.

Slingerland (*1902*) made extensive studies in New York on the kinds of insects caught in light-trap lanterns in 1889 and 1892. The detailed lists of traps catches included in an appendix to the bulletin are particularly important for comparison with the catches of the more recent electric traps.

The development of several trap-lanterns in France using acetylene was reported by Vermorel (*1902*). He called attention to several American kerosene trap lanterns and others of French and Swiss design. He also included for crop

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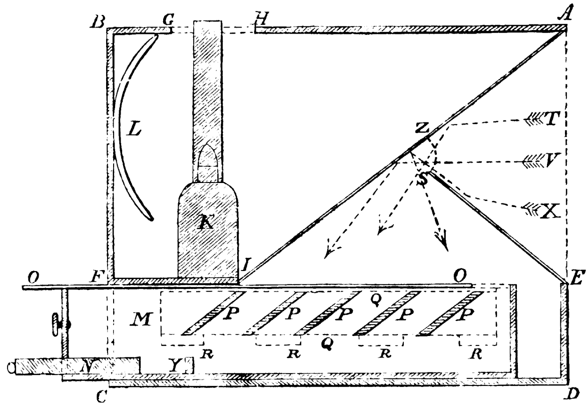
[3]Townend Glover was the first entomologist of the U.S. Department of Agriculture.



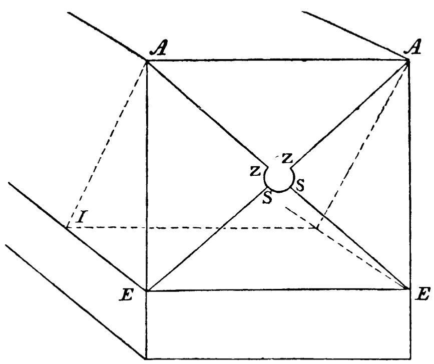
A B C D is a box, having a partition I F for lamp K to rest on, behind the latter being a strong reflector L. The box A B C D is open at A E, also at H G (for lamp chimney to pass through), and at F C for the drawer M.

M is a drawer fitted above with a glass slide O running in a groove; and a Venetian blind-like apparatus P P (the laths of which are kept in position by the side strips indicated by the dotted lines Q Q), dropping loosely on to the side-rests R R. It is also fitted with a small drawer N, the latter being filled with layers of flannel for the reception of chloroform, and stopped by the block Y.

A (Z) I is a quadrilateral sheet of glass, of the width of the box, fixed at the angle shown in the figure.

E S is another piece of glass of the shape of a triangle with the apex cut off.

A E S Z (represented by the lines A Z, E S and dotted lines A E, Z S) are two other bits of glass shaped like E S—the four pieces A I, A E S Z, E S, and A E S Z (No. 2) being arranged and fixed (as shown in accessory perspective figure) in such a manner that, viewed from the point V, they form a hollow four-sided pyramid, the apex of which is wanting, as shown at Z S in both figures.*



T, V, and X are arrows indicating the direction an insect flying towards the lamp K must unavoidably take.

N.B.—Besides the above, it is recommended that the parts of the sides of the box corresponding with the triangles A E I should be lined with glass; and a duplicate drawer, fitted up in every way exactly like the drawer M, should be prepared in readiness for use.

Figure 1.—Glover's new American moth trap from Knaggs (*1866*).

growers a list of noxious butterflies and moths "that could be most easily destroyed by light traps."

Klöcker of Denmark (*1903*) described a trap for catching Lepidoptera, the design of which had originated in Rumania and was then available in Vienna.

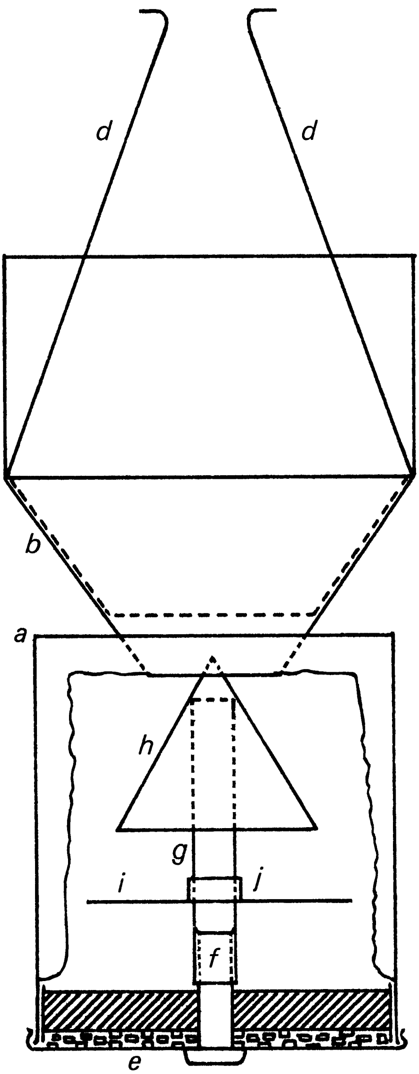


Figure 2.—McNeill (*1889*) insect trap to be used with electric light. *a*, A 3-quart tin pail, 6-½ inches long by 5-½ inches in diameter; *b*, funnel; *c*, baffle, soldered across center of funnel; *d*, steel wires support trap; *e*, pail lid forms trap bottom; *f*, tube; *g*, cylindrical tube; *h*, hollow cone; and *i*, disk.

This consisted of two concentric rings from which was suspended a bag of white gauze for holding the insects. The trap was mounted under a light and held in place by a hanger. The preferred light source was an electric arc lamp, but an acetylene or kerosene lamp could be used.

Attractant equipment continued to change as new light sources were developed. Sanders and Fracker (*1916*) used 40 gasoline arc lanterns set in 5-inch deep, galvanized pans to collect adults of 17 species of the genus Lachnosterna at five stations in Wisconsin during 1914 and 1915. By comparison, a kerosene farm lantern caught approximately 30 to 35 percent as many beetles as the gasoline lantern.

Gross (*1913*) reported the use of an arc-light insect trap to collect numbers of the dingy cutworm moth, *Feltia subgothica* (Haworth), for his studies on the reactions of arthropods to monochromatic lights of equal intensities.

In Ventura County, Calif., in 1914, the operation of eight large electric arc lamps with pans--partly filled with water--mounted beneath and 24 small light traps to trap moths, primarily of the variegated cutworm, *Peridroma saucia (=margaritosa)* (Hübner), was indicated by Bensel (*1916*). The total number of moths captured during the season reached a reported figure of 1 million.

In Montana, a trap was made up of utensils commonly found on farms and which served other purposes when not in use as a light trap (Parker, and others 1921). The trap consisted of a No. 2 galvanized-iron washtub and a No. 2 barn lantern. A galvanized-iron arch was fitted across the tub and served to deflect the moths and to hold the lantern (fig. 3). Eleven such traps caught 82,488 pale western cutworm moths, *Agrotis (=Porosagrotis) orthogonia* Morrison, during the 1920 season.

One of the first recorded insect trap applications using the incandescent electric lamp, invented in 1878 by Thomas Edison, was that by Runner (*1917*). He enclosed the lamp with sticky fly paper to trap attracted cigarette (tobacco)

Figure 3.–Montana light trap, designed in 1919.

beetles, *Lasioderma serricorne* (Fabricius). He noted that the adult beetles flew "more readily to blue or violet light than to red or orange."

Lepidoptera were collected in light traps devised and used, in 1916 and 1918 by Turner (*1918, 1920*), to determine the relative proportions of male and female moths attracted to the light and the percentage of gravid females among those taken. Turner used an arc lamp, hung in an inverted, truncated cone of heavy tin, as the attracting light. One-half of the cone, which would otherwise encircle the lamp, was cut away; the narrow (lower) end of the cone was fitted into the opening in the top of the trap. Immediately below this opening several plates of glass were arranged at angles to direct the moths downward into the body of the trap. The trap was 12 by 14 inches at the base and 20 inches high. Hydrocyanic acid gas, generated within the trap, was used to kill the moths.

Several years later, Williams (*1923*) developed "a new type of light trap for insects" for portable use on cotton pests in Egypt. A very important feature was the visibility of light in all directions. Another characteristic was its availability for electricity or acetylene without serious alteration. Carbon tetrachloride was selected as the killing agent with acetylene fuel.

ELECTROMAGNETIC RADIATION AND INSECT RESPONSE

Historically, visible light as an attractant to insects was investigated much earlier than other regions of the electromagnetic spectrum. Visible radiation is that part of the electromagnetic spectrum to which the human eye is sensitive, that is, the region from 7,600 to 3,800 angstrom units (A.) or 760 to 380 nanometers (nm). The succession in which various illuminants were used to attract insects–fire or torch; candle; kerosene lamps and lanterns; and carbon-filament, incandescent electric lamp–is the same as the order of their increase in color balance, or "whiteness," (Kunerth *1919*). The electric arc lamp and gasoline and acetylene mantle lamps provided light that was more nearly white than the preceding lamps that provided yellow light. More recently developed lamps can furnish white or various colors of light as desired.

Relation of Insect Response to Wavelength

An early observation of insect reaction to radiation beyond the visible was made by Lubbock (*1882*) "that ants are not sensitive to the ultra-red rays; but on the other hand, that they are very sensitive to the ultraviolet rays which our eyes cannot perceive." The validity of such observations is confirmed by the vast amount of scientific literature concerned with visible and ultraviolet radiation and insect responses to it. This work has established that the range of responses for some insects extends into the ultraviolet region to somewhat below 300 nm, Goldsmith (*1961*); and, whereas human visual acuity peaks at about 556 nm, peak response of many insects occurs in the near ultraviolet at about 365 nm (Hollingsworth *1961*, *1964*; Weiss *1941*, *1943*).

Some insect species have shown peak responses to light in the 490- to 520-nm range (Goldsmith *1961*; Hollingsworth *1961*, *1964*; Stermer *1959*; Weiss *1941*, *1943*, *1944*). In some cases, this range was a secondary peak and in others it was the primary peak, depending on luminous flux density. Physiological as well as physical and other factors influence the phototaxis of insects (Williams *1939*; Ficht and Hienton *1941*; Hartsock *1961*; Tashiro *1961*; Deay *1961*; Kovrov and Monchadsky *1963*).

Electric Lamps Used and Their Characteristics

Numerous lamps have been used singly or in combination to determine photo responses of various economic insects during the past 25 years. These lamps were selected to provide a wide range in radiation output in terms of quality (wavelength) and quantity (power). Most of these lamps were commercially available. Those included were: inside-frosted incandescent—15-watt (w.), 75-w., 150-w., and 300-w.; gaseous discharge—100-w. H-4 mercury vapor, 15-w. germicidal, and 2-w. argon glow; and fluorescents--15-w. size of blacklight (BL), blacklight-blue (BLB), blue, green, green-photo, daylight, white, and pink; 20-w. sunlamp and experimental pink; 30-w. blacklight filtered; 6-w. BL; and 22-w. and 32-w. BL circlines.

The differences in radiation emitted from these various lamps should be considered in evaluating the results. Each of the three major types has substantially different output characteristics. The standards of measurement and terminology commonly employed for the ultraviolet, visible, and infrared regions of the electromagnetic spectrum also differ.

Incandescent lamps produce radiation by heating a tungsten filament. The resulting continuous spectrum includes a small amount of ultraviolet, considerable visible light especially rich in yellow and red, and a peak of radiation in the infrared region which includes about three-fourths of the total lamp output.

Gaseous discharge lamps produce radiation from excitation of gas molecules in the form of an arc, or plasma, by passage of an electric current through the gas. Each gas produces its own characteristic pattern of colors, giving a noncontinuous spectrum of bright lines at particular wavelengths. The intensities of these lines in the lamp output can be controlled by adjusting the pressure within the lamp and by changing the glass envelope which may filter out certain wavelengths. Gaseous discharge lamps included in the comparisons were the 100-w. H-4 mercury vapor, the 15-w. germicidal, and the 2-w. argon glow lamps. The germicidal lamp is a mercury vapor lamp using a much lower vapor pressure than the H-4 which increases radiation in the short-wavelength ultraviolet region. Mercury vapor lamps produce primarily ultraviolet, blue, and green radiation with little red. The proportion of infrared radiation is much smaller than that of incandescent lamps.

Fluorescent lamps are fundamentally a modification of the gaseous discharge lamp. The basic lamp structure is a low-pressure mercury vapor tube, essentially identical to the germicidal lamps tested. The inner surface of fluorescent lamp envelopes is coated with various phosphors which absorb short wavelengths and reradiate the energy at longer wavelengths; thus the term "fluorescent." Certain phosphors fluoresce in the ultraviolet region and others at various wavelengths in the visible spectrum. The spectral output of fluorescent lamps includes the continuous spectra from the fluorescing phosphors plus the bright lines from the mercury vapor discharge shining through at particular wavelengths.

Traditional measurement terminology was developed for visible light but is not particularly suited for use with other wavelengths. The terminology is further complicated because certain measurement units for visible light include compensation for the visual sensitivity of the human eye, which is most sensitive to yellow and green radiation. The foot-candle (ft.-c.) is one such compensated unit.

The velocity of all electromagnetic radiation is approximately 186,000 miles, or 300,000,000 meters, per second. This constant velocity is always the product of frequency times wavelength, $F\lambda = c$. Therefore, the units of linear measurement suitable for wavelength differ in various regions of the spectrum. The relations of some of the common units used for the wavelengths under discussion are: 1 millimicron (mμ) = 1 nanometer (nm) = 10 angstrom units (A) = 10^{-9} meters.

Lamps emit energy at a definite rate, so their output is properly measured as radiant power in watts. In confining these measurements to some unit of space, the unit solid angle, or steradian,[3a] is often used.

Light or luminous flux is defined as visually evaluated radiant energy. The unit commonly used to measure this visible energy is the lumen (lm), defined as the light, or flux, emitted through one steradian by a uniform point source of one standard candle. This power measurement is analogous to watts per steradian. Manufacturers publish total lumen output ratings for all common types and sizes of lamps used for illumination. Consequently, when these ratings are known, a spectral distribution curve indicating power distribution per lumen for a particular type of lamp can be used to evaluate all the various sizes.

Radiation Emission From Lamps Used in the Studies

Data describing most of the lamps used in these studies were published by the General Electric Company in GE 1964 Large Lamp Catalog; GE 1964

[3a] Steradian: A solid angle subtending an area on the surface of a sphere equal to the square of the sphere's radius.

Fluorescent Lamps Performance Data Bulletin LD-2 (Staley, *1960*); and Bulletin LD-1 (Weitz *1946*) and (Weitz *1956*).[4]

In the development of these spectral energy distribution curves, General Electric analyzed the lamp output radiation with spectroradiometers which disperse the radiation and measure the radiant power by scanning the spectrum with a slit passing a 10 nm wave band. A curve may be plotted from the data in the same way a distribution curve is plotted from the individual points measured at the center of zones. The curves were supplied on a basis of wavelength versus radiant power per 10-nm band per lumen for lamps emitting primarily in the visible, and wavelength versus radiant power per 10-nm band per watt of input for lamps producing primarily ultraviolet. The figures presented herein pertain to the particular lamps tested and were computed from the data supplied by General Electric Company, hereafter abbreviated GE. Except for the incandescent, they include the visible and ultraviolet regions of the spectrum and are based on initial total lamp lumens, indicating the power emitted from the particular size lamp over the range of wavelengths plotted. All data presented in this discussion are related to production-run lamps and should be considered on the order of ±10 percent from actual output.

The radiant power emitted from a 75-w. GE, inside-frosted, incandescent lamp (fig. 4) is divided to indicate the ultraviolet (to 380 nm), visible (380-760 nm), and infrared (beyond 760 nm) regions of the spectrum. Radiated wavelengths longer than 5,000 nm are absorbed by the glass blub.

The bulb, base, and socket assembly radiate heat at wavelengths characteristic of their operating temperature. The spectral distributions of the other incandescent lamps used in these comparisons are similar to those of the 75-w. lamp with the difference primarily in radiant power output. Comparative initial lumen outputs are: 15-w., 144 lm; 75-w., 1,180 lm; 150-w., 1,750 lm; 200-w., 3,940 lm; and 300-w., 6,300 lm.

The distribution of power output from the 100-w. GE--H-4 mercury vapor source is shown in figure 5. The total radiant power in the line type spectrum was about 16 watts.

The 15-w. GE germicidal lamp (G15T8) (fig. 6) is a low-pressure mercury arc discharge lamp with about 60 percent of the radiant power emitted at its predominant wavelength, 253.7 nm. Because no fluorescent chemicals coat the inside of the clear quartz bulb, the radiation is emitted by the lamp.

Spectral distribution curves for the blue, green, daylight, white, and pink 15-w. GE fluorescent lamps (F15T8) used in these comparisons are also shown in figure 6. Comparative initial lumen outputs of these lamps are blue, 350 lm;

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[4]Additional information, especially the spectral energy distribution curves, was obtained in personal correspondence from R. L. Paugh, specialist, Agricultural Lighting and Illuminating Engineer, General Electric Company, Cleveland, Ohio.

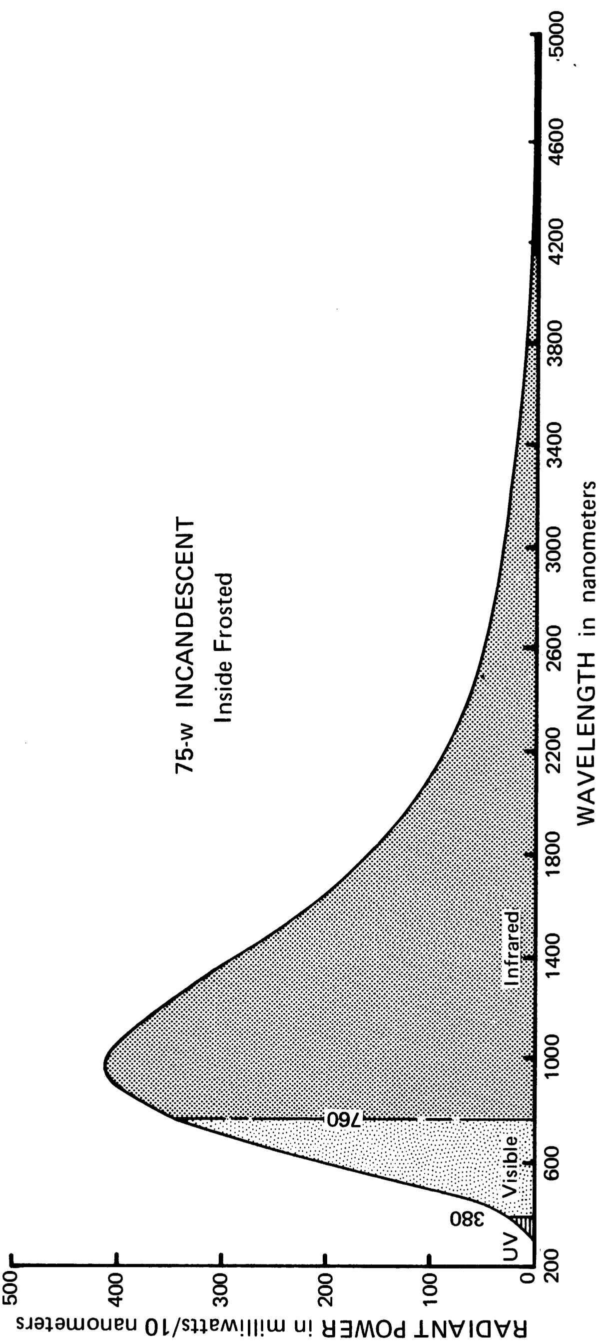

Figure 4.—Graph of radiant power emitted from a 75-w. GE, inside-frosted, incandescent lamp.

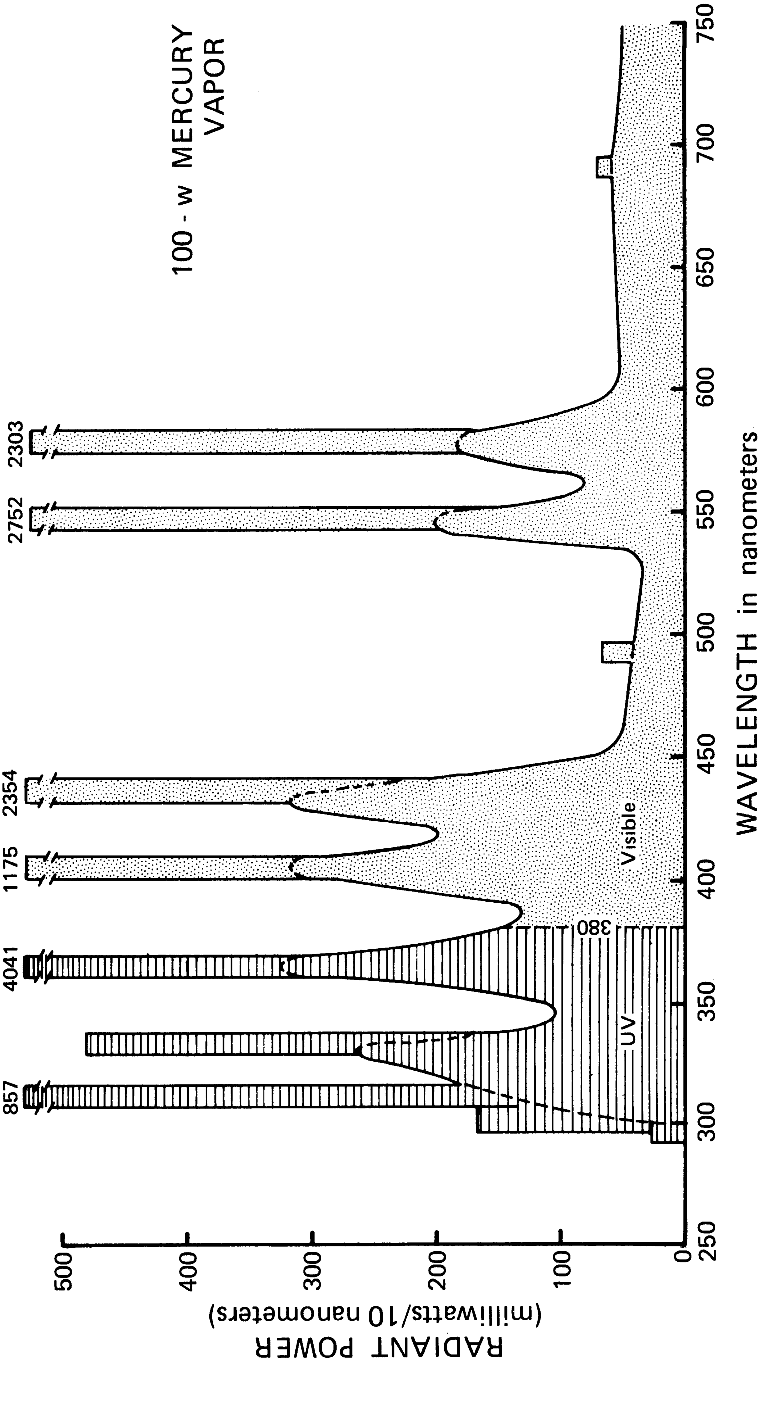

Figure 5.–The distribution of power output from the 100-w. GE–H-4 mercury vapor source.

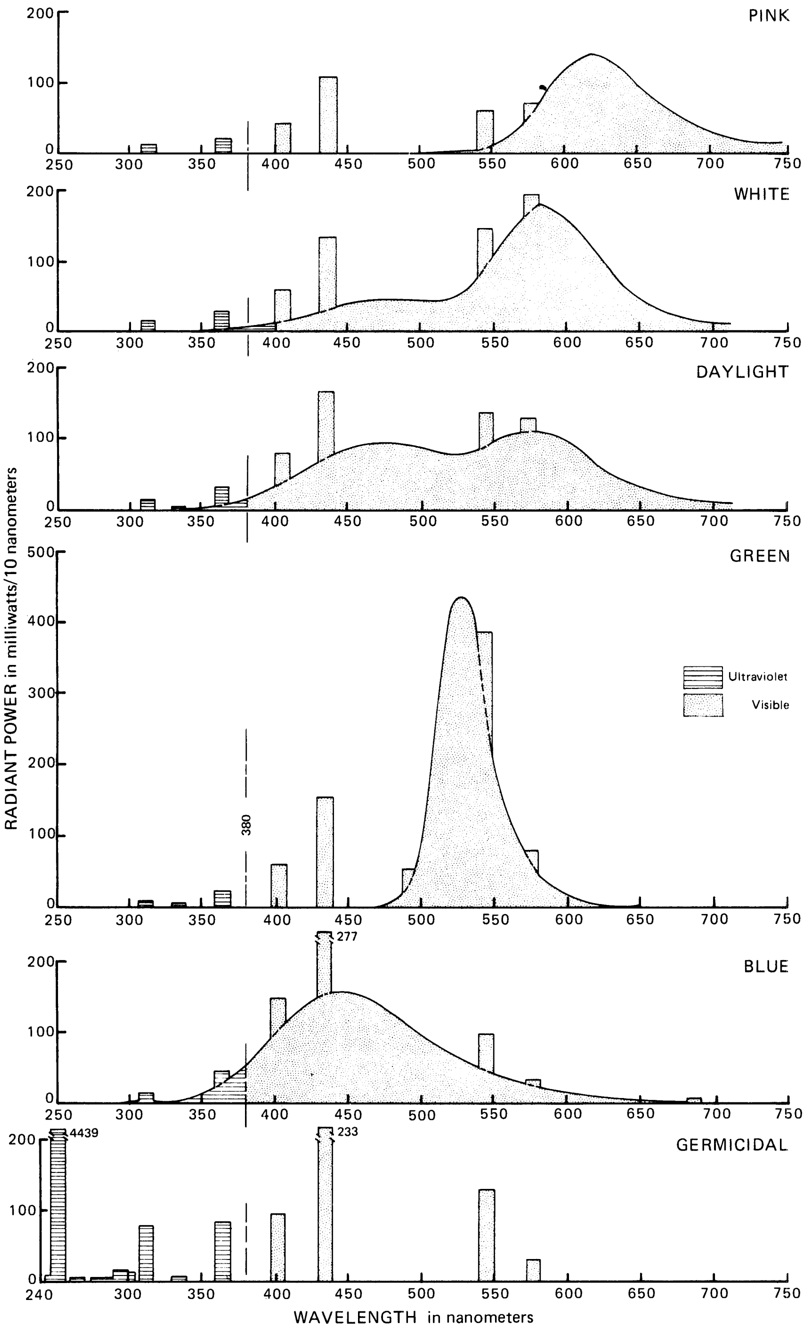

Figure 6.—Spectral distribution curves of various fluorescent lamps and 15-w. GE germicidal lamp (G15T8).

green, 1,248 lm; daylight, 670 lm; white, 810 lm; and pink, 350 lm. The spectral distribution of the green-photo lamp is identical to the green. The green photo is approximately 15 percent more efficient than the standard green, thereby having a greater radiant power output.

Blacklight is a popular name for ultraviolet radiant energy within the range of wavelengths from 320 to 380 nm. Fluorescent blacklight lamps (BL and BLB) use a phosphor which converts the 253.7 nm energy of the basic mercury arc discharge to longer ultraviolet wavelengths. The conventional GE 15-w. BL lamp (F15T8-BL) emits approximately 2.6 watts total radiant power in the distribution shown in figure 7. This lamp was available until about 1961 when the phosphor was changed to a Philips' type (European), total power emitted 3.7 watts, also shown in figure 7.

The 6-w. GE blacklight lamp (F6T5-BL) had the same spectral distribution as the 15-w. with the conventional phosphors. The 22- and 32-w. GE blacklight circline lamps (FC8T9-BL and FC12T10-BL) also had the same spectral distribution as the 15-w. with conventional phosphors. Relative blacklight energy data for these lamps based on the F40 BL fluorescent as 100 are 6-w., 7; 15-w., 25; 22-w. circline, 38; and 32-w. circline, 63. The data represent radiation from 320 to 420 nm.

The GE 15-w. blacklight-blue lamps (F15T8-BLB) (fig. 7) are self-filtered with red-purple bulbs to absorb the visible radiation. The spectral output of the 20-w. GE fluorescent sunlamp (erythemal F20T12) was similar to the 40-w. sunlamp which peaks between 310 and 340 nm and has a range from 280 to 460 nm. The general shape of the distribution curve should be similar to that of a fluorescent BL lamp.

In some comparisons a single fluorescent lamp was over-energized with a special ballasting arrangement consisting of parallel-connected ballasts to increase the current flow and wattage to get more brightness per unit area, or radiant power per lamp. This procedure, however, gives descreased radiant power output per watt of input and markedly shortens lamp life.

The 2-w. argon glow lamp is an electric-discharge lamp in which blue, violet, and near ultraviolet radiant energy is generated in the space close to the electrodes. The spectral emission curve for this lamp is shown in figure 8.

Several other lamps, described below, were used in light trap investigations and are mentioned later.

Mazda was a trade mark for incandescent lamps adopted in 1909 by the General Electric Company. By 1927 it was used by more than one manufacturer, and filaments of all such lamps were made of tungsten.

Mazda B was a vacuum lamp.

Mazda C was a gas-filled lamp.

Mazda CX was a gas-filled lamp with a special glass bulb that transmitted most of the ultraviolet radiation emitted by the tungsten filament.

G-1 was a low-pressure mercury-arc lamp that consumed approximately 50 watts. It radiated ultraviolet radiation and visible radiation shorter than 600 nm.

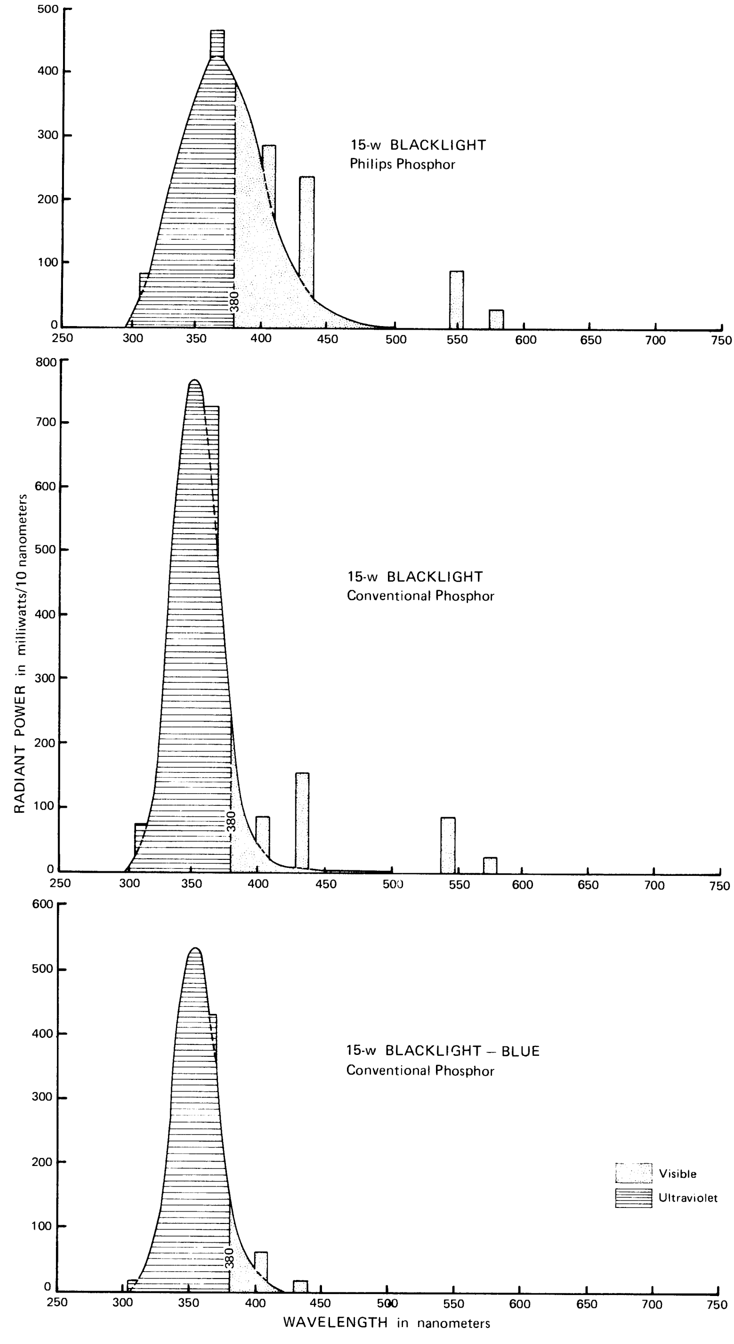

Figure 7.–Radiant power distributions of fluorescent blacklight lamps with different phosphors.

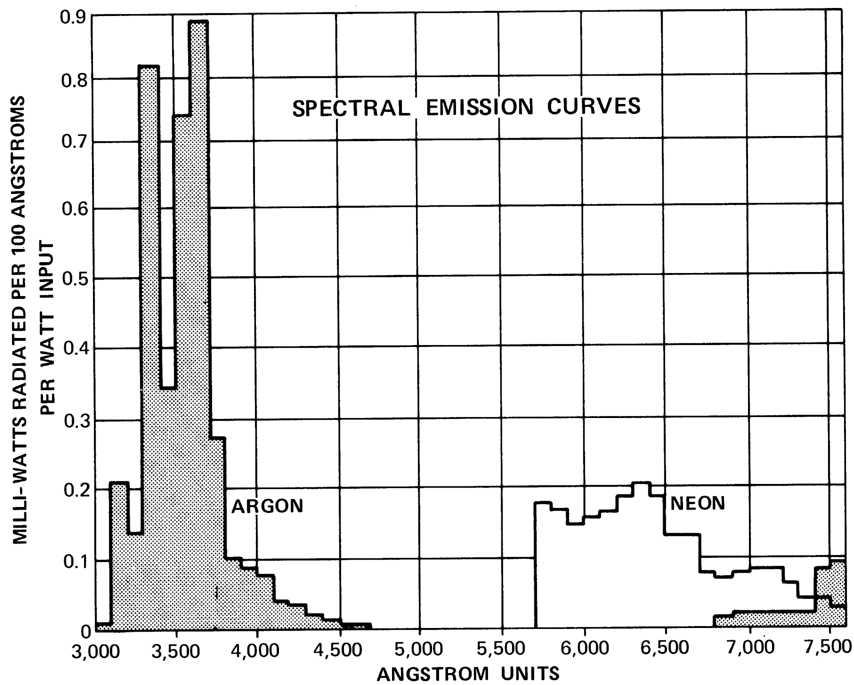

Figure 8.—Spectral emission curves for argon glow and neon glow lamps.

G-5 was a mercury-arc lamp that consumed approximately 100 watts and radiated ultraviolet energy from 280 nm to the edge of the visible spectrum of approximately 400 nm.

H100-SP4 was a spot-type mercury vapor lamp.

Mercury vapor lamps of the types HQA 125 w. and HQL 250 w. are made by VEB Berliner Gluhlampenwerk.

GENERAL TYPES OF ELECTRIC INSECT TRAPS

Currently designed insect traps that utilize an electric lamp as the attractant are frequently classified into three types or groups: (1) the electrocutor or electric grid. (2) the suction- or fan-type trap; and (3) the gravity or mechanical trap.

The first type and usually the second type require 110-volt electric service. Of the third type a large number also operates directly at 110 volts, while a small number is powered by storage batteries and dry cells.

The design for a light trap and mechanical aspirator, operating on dry cell batteries, was reported by Nelson and Chamberlain (*1955*). An improved model of this miniature New Jersey-type (detailed later) light trap for 6-volt battery operation was described by Sudia and Chamberlain (*1962*). Traps of the latter design are in commerical production and are known as the CDC (Communicable Disease Center) miniature light trap.

Operation of gravity-type light traps at locations remote from central station electric service may require a dependable, portable source of 110-volt, 60-cycle alternating current to energize the attractant lamp. A transistorized power supply and automatic photo-switch control unit for battery operation of survey-type electric insect traps was designed, built, and operated by Hollingsworth and Briggs (*1960*). A timer for controlling periods of light trap operation and a similar self-contained power inverter were developed by Wagner, Barnes, and Ford (*1969*).

Electrocutor or Electric Grid-Type Trap

The electrocutor or electric grid-type of light trap consists of a series of parallel wires, with adjacent wires insulated from each other and connected to opposite polarities of a low-current high-voltage transformer. The assembly of charged wires is most frequently made in the form of a flat panel or circular cage with provision for an attractant lamp. An insect in flying between the wires draws an arc that passes through its body usually causing death.

Dalziel (*1951*) has stressed that an exposed, high-voltage, electrocuting grid, incorporated into an electric insect trap is a potential shock and fire hazard. He indicated further that, although little is known about the phenomena of insect electrocution, efficient electrocution of small insects may be accomplished when these hazards have been reduced to an acceptable degree by proper trap design, construction, and installation.

Dalziel concluded from his own research and that of Tavernetti and Ellsworth (*1938*) that the maximum practical voltage for an electric insect trap with an exposed electrocuting grid is about 7,500 volts. He said such a trap, constructed from approved components, supported at least 7 ½ feet above the ground or floor, and limited to a maximum current output of 15 milliamperes, rms (root mean square, or effective value) should be a reasonably safe device.

In earlier studies, Mehrhof and Van Leeuwen (*1930*) found that the most satisfactory results for killing Japanese beetles, *Popillia japonica* Newman, were obtained with a frequency of 60 cycles and from 10,000 to 12,000 volts. Operating a trap in 1928 at this frequency and voltage range with the grid wires spaced five-eighths of an inch apart, they reported practically all collected beetles dead within 48 hours.

In other experiments, Tavernetti and Ellsworth (*1938*) determined the electrical requirements for the efficient operation of electrocuting devices when used on the greenbottle fly *Phaenicia (=Lucilia) sericata* (Meigen), and potato tuberworm moth, *Phthorimaea operculella* (Zeller). These insects are relatively small, with a wingspread between one-fourth and one-half inch.

From their studies conducted with the two insects, these men concluded that there is a definite range of current, depending upon the voltage and space between the grid bars, that will give a satisfactory insect kill on an electrocuting grid. Furthermore, satisfactory kills were obtained with currents less than 5 ma., and the current-voltage curves for a 75-percent kill of insects and for the breakdown of the air gap between bars were similar. These indicated that the current and voltage requirements are governed by the amount necessary to create an arc rather than to kill the insect.

Taylor and others (*1951*) found that electrocutor traps with a 3/8-inch, center-to-center grid spacing and impressed voltages of 3,500-4,500 were most effective for killing flies. However, such equipment was unsatisfactory for outdoor use with improved attractant lamps because the high volume of insects clogged the grid openings. From tests in Iowa and Indiana, they determined that a grid spacing of 5/8-inch center to center was most satisfactory in field use for killing the European corn borer, *Ostrinia nubilalis* (Hübner), and similar insects.

The increased grid spacing required voltages higher than those used on fly grids. Tests showed that values between 7,000 and 9,000 volts were satisfactory and determined that grids should be operated at a voltage level just below arc-over for maximum effectiveness. This result was in agreement with the work of Tavernetti and Ellsworth (*1938*).

Higher voltages impressed on the grids caused breakdown of the grid insulators. Design data for insulator performance had not been computed for insulating materials subjected to the conditions of moisture, dust, and insect residues which occur when used in light traps.

In 1952, Taylor, with assistance from D. L. Calderwood, conducted tests with eight different insulating materials installed in light traps with 6,000-volt transformers in field tests in Indiana, Iowa, and Florida. Their conclusions from this work (unpublished)[5] were that (1) The effectiveness of electrocutor grids equipped with transformers, now available, is seriously impaired anytime the grid to grid resistance is as low as one megohm; (2) with a grid to grid resistance of 5 megohms, the traps appeared to be as effective as they were when the grid to grid resistance approached infinity, and (3) glazed (wet process) porcelain, lucite, and alsimag insulators were found to be completely satisfactory during the period of the test. The manufacture of more effective insulators and transformers has improved the performance of electric grid insect traps. Insulators of polystyrene and Teflon, developed since Taylor's work, have shown good properties.

The electrocutor-type insect trap is commonly used for insect destruction purposes. It is widely used in attempts to eliminate or control nuisance insects around residences, business establishments, and food processing plants (fig. 9).

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[5]Unpublished reports, cited in the text by the author's name (unpublished) are on file in the Agricultural Structures and Electrification, National Program Staff, Agricultural Research Service, USDA, Beltsville, Md. 20705.

The arc action between grid wires may cause burning or other bodily damage to insects passing between the wires making insect identification difficult. For that reason, this type of trap is seldom used for insect surveys.

Suction- or Fan-Type Trap

Suction- or fan-type electric insect traps were developed to fill the need for insect attracting and capturing equipment beyond that provided by an electric lamp and a simple collecting device. Equipment was needed particularly for catching small, agile fliers which tend to hover near the lamp or alight on the baffles. The earlier suction- or fan-type electric traps were first developed for survey, control, or both, of specific species or families of insects—in particular, the Clear Lake gnat, *Chaborous astictopus* Dyar and Shannon, mosquitoes (Culicidae), and the cigarette beetle.

All ordinary light traps proved futile for trapping the winged, Clear Lake gnats because the traps soon became hopelessly clogged with these insects. Herms and Burgess (*1928*) added a suction device in addition to the attractant

Figure 9.—Electric grid insect trap installation in food processing plant.

lamp. A suitably designed, small electric fan was selected for that purpose. A modification of this original trap, known as the Akins trap, was reported by Essig (*1930*) to be in commercial production for the control of this pest (fig. 10).

The Akins' trap consisted of the following parts: (1) An inverted, funnel-shaped reflector, 18 inches in diameter and provided with a light socket; (2) a 100-w. lamp to attract the gnats; (3) a thin sheet iron sleeve, 15 inches in diameter, suspended about 10 inches from the reflector by three ¼-inch rods, allowing clearance for the gnats to come to this light; (4) a small electric fan with motor, the latter attached to the sleeve and designed to draw the insects down from the light by the action of the fan; (5) a black muslin bag, about 3 feet long, drawn over the lower end of the sleeve.

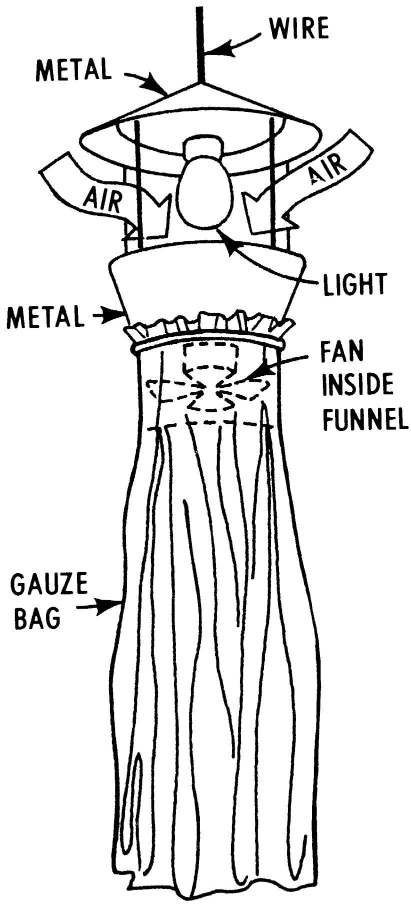

Figure 10.–The Akins gnat trap.

Headlee (*1932*) initiated efforts in 1927 to develop a light trap that would replace humans as collectors for mosquitoes. He produced a device that attracted mosquitoes but in such a limited number that the device did not meet the need. This trap depended upon light alone and operated on a battery. Three years later, Headlee produced an experimental suction light trap that operated on 60-cycle, 110-volt alternating current.

Initially, this suction light trap was equipped with a tube—30 inches long and 9 inches in diameter—mounted horizontally. A small, 8-inch fan was installed about 8 inches from one end. In front of this fan was placed an electric light socket backed by a reflector. The fan was used to create suction from the lighted end of the tube. A cloth mosquito-net bag was placed over the opposite end of the tube. Enough mosquitoes were caught so the trap could be used to replace human collectors. Within 2 years the trap was converted from horizontal to vertical operation as reported by Mulhern (*1934*). A 25-w., 110-volt, inside-frosted incandescent lamp was selected as the attractant. This trap (fig. 11) with slight modifications is commercially produced as the standard New Jersey mosquito trap[6] (Mulhern *1942*).

Efforts by Runner (*1917*) to attract adult cigarette beetles to electric lamps and capture them in sticky fly paper were followed by an additional research effort to attract this insect to a light trap. Reed and others (*1935*) reported the development of a suction light trap in 1932 for attracting and collecting these beetles.

This trap consists of three main parts—the flange, the barrel, and the cone—in addition to an attractant lamp and a fan (fig. 12). The flange is 21 inches in diameter at the outer edge and 12½ inches where it is soldered to the barrel of the trap. The flange supports an electric lamp and serves to increase the flow of air through the barrel and also to reflect the light. The galvanized iron barrel is cylindrical, 13 inches in diameter, 12 inches long, and is mounted horizontally. Riveted inside the barrel is a steel bracket to which is attached a 1/20-hp. motor. The motor is connected to two 12-inch fan blades and is positioned in the barrel so as to locate the fan centrally. The cone made of 20-mesh steel or copper screen wire is attached to the rear end of the barrel, and terminates in a small opening which accommodates a quart glass jar. The lamp, originally found most satisfactory for use in the trap, was a 50-w., mill-type, incandescent bulb, constructed for rough service. The trap as described, with minor changes, is in common use in many tobacco storage warehouses in North Carolina and Virginia.

The three suction- or fan-type electric traps described were the earliest developed in the United States, and are mentioned to illustrate this type of insect light trap. Changes in their design and utilization will be treated in later discussion.

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[6] Manufactured by Hausherr's Machine Works, Toms River, N.J.

Gravity or Mechanical Trap

The gravity or mechanical trap is the third type of insect trap that uses an electric lamp as the attractant. It differs from the electrocutor type in that it has no high voltage for killing insects and from the suction-type trap in that it has no motor-driven fan. Thus, its capture of insects depends entirely on the attractant lamp and the trap design. Insect collectors have used the gravity type most often because the insects captured were less damaged and more easily identified.

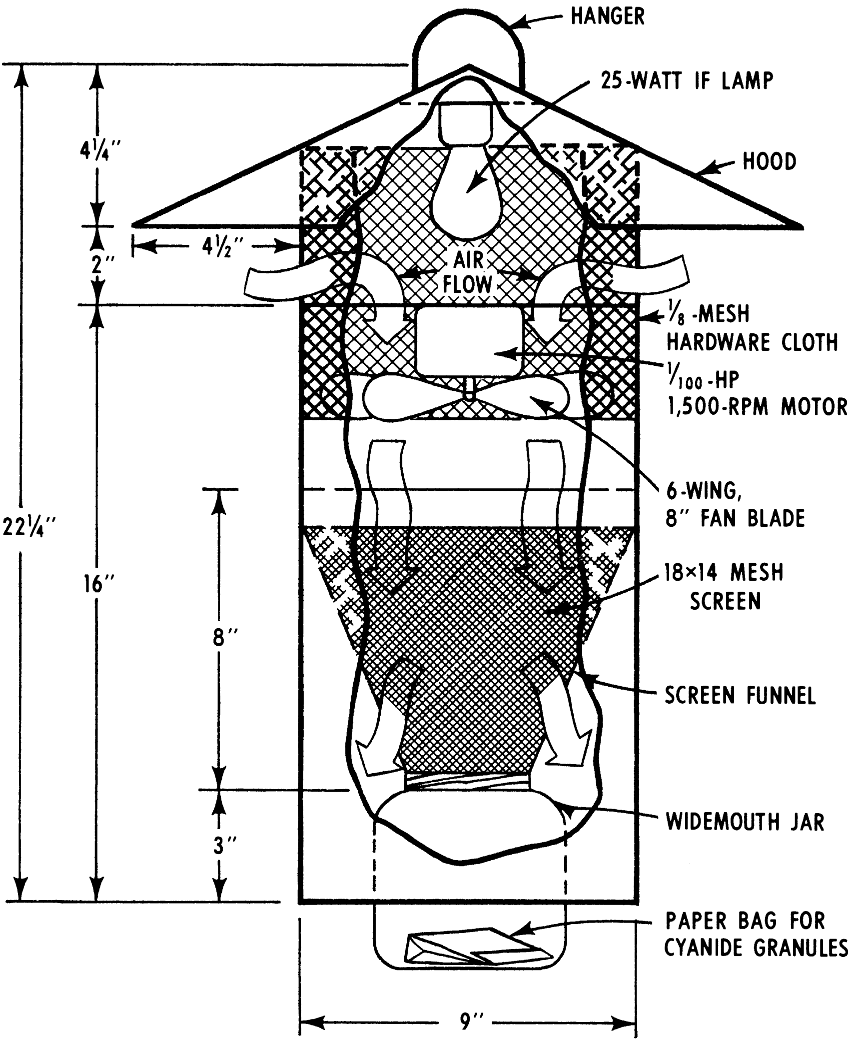


Figure 11.–Cutaway view of New Jersey mosquito trap.

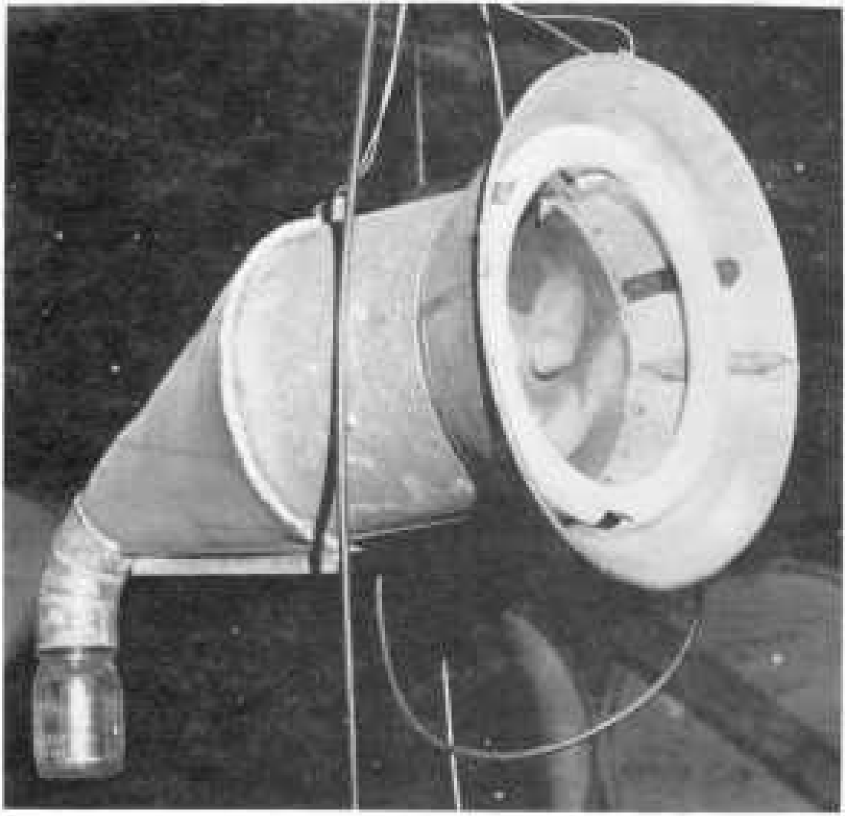


Figure 12.—Suction-type insect trap and BL lamp.

The development of several insect traps of this type has been listed earlier. The traps attributed to McNeill, Gross, Turner, and Williams were equipped with some killing agent, such as chloroform, for immobilizing or killing the attracted insects because their identification was important. Electric traps that were utilized by Bensel (*1916*) and Runner (*1917*) were designed to capture the maximum number of insects by using pans filled with water or sticky fly paper to collect them.

Studies of insect catches in orchards by Parrott (*1927*) and of the Oriental fruit moth, *Grapholitha molesta* (Busck), by Peterson and Haeussler (*1926*) were made with traps in which pans, filled with water and a film of oil, were fastened below an electric lamp. Farmers in Virginia and Alabama used similar equipment (CREA *1928*) to control the tomato fruitworm. This type of trap was very simple, consisting of a reflector, lamp, and water pan (fig. 13).

Hallock (*1932*) reported the results of 5 years' work on the development of light traps for catching adult Asiatic garden beetles, *Maladera (=autoserica) castanea* (Arrow). His comparison in 1927 of a trap using a lantern hanging over a tub of kerosene with another using a 100-w. electric lamp over a tub of water with an inch of kerosene revealed catches of 217 and 2,947 beetles, respectively. The addition of a funnel beneath the lamp in 1928 and baffles above the funnel in 1931 changed the appearance of the trap and improved beetle catches.

Hallock (*1936*) reported further refinements in the funnel and attachment of a pint jar to the bottom of the funnel to catch the beetles. He compared the attractiveness of various lamps in the laboratory and found "that lights of short wavelength near the violet end of the spectrum are most attractive to the beetle." From this work, two traps of similar construction were developed and designated as the large trap and small trap (Hawley, *1936*). The small trap is shown in figure 14. The absence of a roof, permitting wide light radiation, and use of baffles were innovations in trap design.

A new light trap, reported by deGryse (*1933*) included a bucket-shaped receptacle into which were closely fitted a set of four movable trays pierced with circular openings which gradually decreased in diameter. The openings in the topmost tray were five-eighths inch in diameter; those in the second tray, one-fourth inch; and those in the third tray, one-eighth inch. The fourth tray was made of a fine-mesh, copper screen. The screens were effective in separating the insects according to size and in preventing excessive packing and

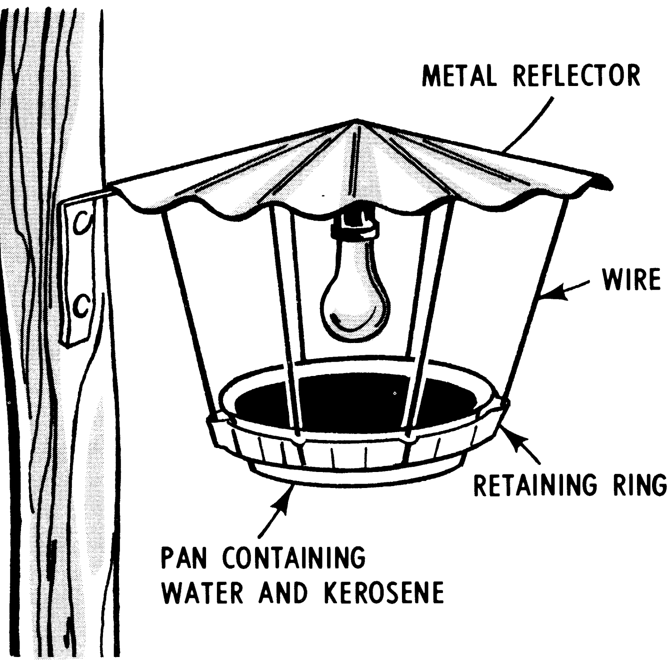


Figure 13.–An early light trap used in Alabama to protect a tomato crop.

Figure 14.—This small trap, developed by Hallock for catching the Asiatic garden beetle, included a 100-w. daylight bulb and four baffles.

subsequent mutilation of the specimens inside the container. Each tray was provided with a small container of absorbent cotton into which the killing agent was poured. Two glass plates were mounted on opposite sides of the 24-inch collecting funnel to reduce circling of the lamp by attracted insects.

The major number of such traps utilized in the United States before World War II comprised the gravity-type electric insect traps previously mentioned, a trap designed and utilized by Walkden and Whelan (*1942*) for owlet moths (Phalaenidae), and the Minnesota trap described by Nagel and Granovsky (*1947*).

DEVELOPMENT OF LIGHT TRAPS FOR INSECT SURVEYS

Light traps were used by Dirks (*1937*) to obtain life history data of numerous species of Macrolepidoptera at Orono, Maine, 1931-34, inclusive. Dirks used incandescent lamps of 200-w. clear and 500-w. and 1,000-w. inside-frosted types and a GE S-1 sunlamp as attractants, plus a pan of water with a kerosene film to trap the moths. He observed a fairly close relationship between outdoor temperature and the number of moths captured. When the average night temperature was 40° to 42° F., few or no moths were taken. In contrast, large numbers of moths–sometimes hundreds of specimens–were taken when night temperatures was 58° or above and other conditions were favorable.

At temperatures between 45° and 53° F., all the light sources tested were approximately equal in value for capturing moths. Above 53° the S-1, a standard 400-w. tungsten mercury arc lamp with a bulb transmitting radiant energy longer than 280 nm, was found superior to the other lamps used. The S-1 sunlamp consisted of a mercury arc between tungsten electrodes with a tungsten filament in parallel with it. At all temperatures, the 1,000-, 500-, and 200-w. incandescent lamps were nearly equal in their capacity for attracting moths. The author stated that "it is evident that the increased attractiveness must have been due to the light-rays peculiar to the mercury vapor bulb or sunlamp." Since the sunlamp radiated more energy in the ultraviolet region and less in the visible than the other lamps, the difference in attraction may have been due to the additional ultraviolet radiation.

Walkden (*1942*) pointed out that "light traps offer an efficient means of obtaining information regarding the distribution, seasonal flight periods, and peaks of abundance of various insect species. Further, that the data obtained from these traps are basic to, or of value in, the consideration of cultural control and other methods for the suppression of the various pests involved." His survey dealt primarily with the owlet moths (Phalaenidae) infesting the Missouri Basin area and was made at six locations in Kansas and Nebraska during the 4-year period, 1934-37.

The light traps used in the six locations were similar except that one had a shallower cone and glass buffers about the lamp. The trap design (fig. 15) included an inverted, galvanized-iron cone, 2 feet in diameter, with a roof of the same material. The lamp was suspended in the center just above the cone rim, and a fruit jar was attached to the bottom of the cone for receiving the insect catch. Clear, incandescent lamps (500-w.) were used at two locations and inside-frosted incandescent lamps (200-w.) at the other four.

Although trap locations differed somewhat, flight trends of individual insect species were the same in all locatities. In the 4-year period, 305 species of Phalaenidae were taken, totaling more than 525,000 individuals. Approximately 90 percent of the specimens taken were of economically important species. Over 36,000 individuals were examined for sex, and 35 percent were found to be females. Differences in seasonal abundance of multiple-generation species were indicated for several important pests since the traps were operated from March to November. Results of this light trap survey may well have influenced a resumption of survey trap use in Kansas, in 1955, when a new survey trap became available.

Taylor and Deay (*1950*) made laboratory tests in 1948 on the relative attractiveness of various gaseous discharge lamps to the European corn borer moth and concluded that the maximum attractiveness for this moth (at the intensity levels studied) was in the near ultraviolet region between 320 and 380 nm. They also reported that among other insects attracted were the adults of the tomato hornworm, *Manduca quinquemaculta* (Haworth), the tobacco hornworm, *Manduca sexta* (Johannson), and the corn earworm, which were attracted in great numbers to sources radiating in the near ultraviolet.

Unidirectional Trap

The success in attracting adults of several insect species to near ultraviolet (blacklight) radiation led to a survey in an Indiana market garden area of the insects of economic importance that were attracted to sources of various wavelengths of radiant energy. A survey trap (fig. 16), with exposed fluorescent type lamps as attractants, was developed in 1951. It consisted essentially of an exposed lamp mounted horizontally at the top with a funnel

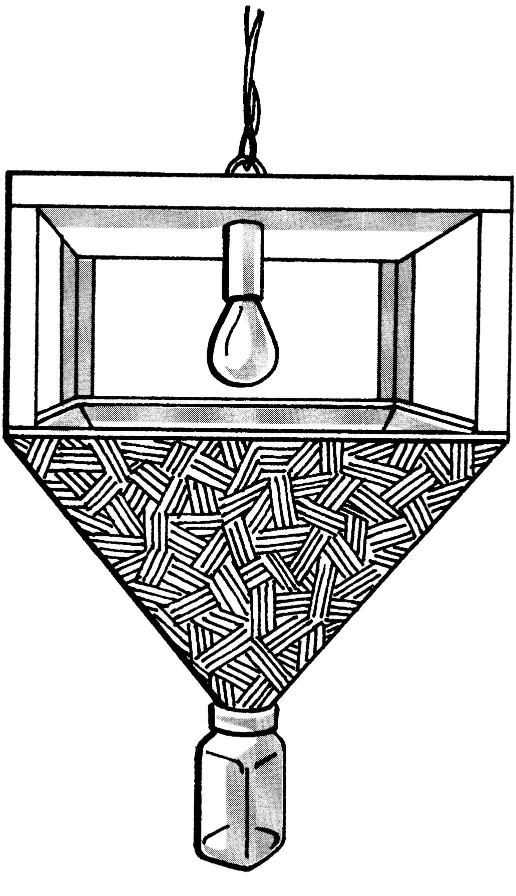


Figure 15.–Light trap used to attract owlet moths in Kansas and Nebraska, 1934-37.

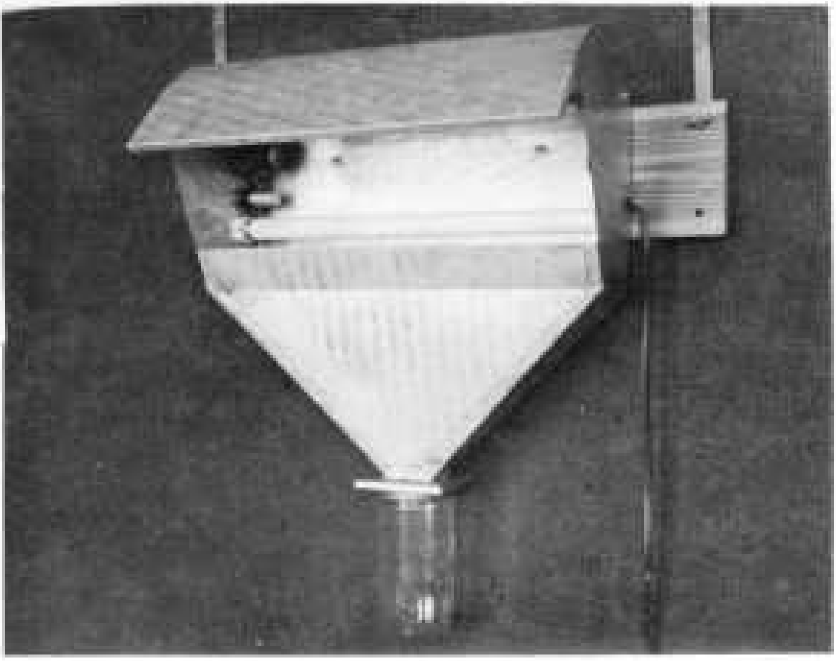


Figure 16.—Unidirectional insect survey trap with 15-w. BL, developed in Indiana in 1951.

opening into a collection container beneath. A daily charge of calcium cyanide was placed in the collection container to kill the insects.

Research scientists readily accepted the low-cost, efficient, blacklight-lamp survey trap, designated as a unidirectional survey trap (Taylor and others *1956* and Hollingsworth and others *1963*).

Lamps, selected for the trap, covered the spectrum from the ultraviolet through the visible into the red. Lamps that radiated in the shorter wavelengths included germicidal (far ultraviolet), plus blue, gold, red, and infrared. Taylor and others (unpublished) recorded insect catches in 14 unidirectional traps which showed that the blacklight (BL), erythemal, and blue lamps attracted the most insects, in that order, while the gold and red lamps attracted very few insects.

Funnel-Shaped Trap With Mercury Vapor Lamp

The attraction of the pink bollworm moth, *Pectinophora gossypiella* (Saunders), to ultraviolet radiation was discovered in Texas in 1952 (Glick and Hollingsworth *1954*). This discovery created an urgent need for a survey trap to aid in determining areas newly infested by this pest. The funnel-shaped trap with mercury vapor lamp (fig. 17), designed for and used in research on the

Figure 17.—Funnel-shaped insect trap with 100-w. mercury vapor lamp, developed in Indiana in 1950.

European corn borer in Indiana had made very large collections of the pink bollworm during July and August and was selected to meet this need.

Initially, this trap consisting of a galvanized iron funnel, (30 inches long, 12 inches in diameter at the front, tapering to a 3-inch diameter in rear, and mounted horizontally), was produced in very limited quantity during 1952 for survey work. A vertical rectangular funnel, which was connected to the larger horizontal funnel and mounted beneath and perpendicular to the main funnel, tapered into a fruit jar charged with calcium cyanide. Moths attracted to the lamp were collected in this jar. The 100-w. mercury vapor lamp (GE type H100-SP4) was mounted horizontally at the small end of the main funnel. The trap became known as the mercury vapor trap (Merkl and Pfrimmer *1955*).

The second trap (fig. 18) used in the 1952 investigation to determine the attractiveness of radiant energy to the pink bollworm was equipped with four 15-w. BL fluorescent lamps, and in general, was more effective than the mercury vapor lamps. The trap with BL lamps was a commercially produced, suction-type trap, which had been modified by the addition of a rain hood and a collection funnel. The suction-fan motor was made inoperative to prevent damage to the specimens. The four BL lamps, approximately 18 inches long, were mounted vertically at the top of the trap in a 4-vaned baffle assembly. Each quadrant contained one of the 15-w. lamps so that the radiation covered a full 360 degrees in the horizontal plane. The baffle assembly was mounted on the fan housing, which consisted of a metal cylinder, 16.5 inches in diameter and 14 inches in height, with a flared top 28 inches in diameter. The collection funnel with a cyanide jar was attached to the bottom of the fan housing.

The size and cost of the trap with the BL lamps precluded its use as a survey trap so that as previously indicated the mercury vapor trap was produced for immediate use. However, a smaller trap (fig. 19) designed and constructed late in 1952 by Hollingsworth was operated by Riherd and Wene (*1955*) during the 1-year period from March 1, 1953, to February 28, 1954, at Weslaco, Tex. This trap, like the larger one, was equipped with four 15-w. BL lamps, one in the corner of each quadrant of the baffles. The killing jar used was a standard one-half gallon fruit jar charged with flaked calcium cyanide. The jar was placed on the trap each day at 5:00 p.m. and removed at 8:00 a.m. the next morning. Daily records were made of 40 species for the entire year. In addition, records of moths captured at the light trap without complete record for the year totaled 73 species, while a considerable number of the species of Microlepidoptera and some of the smaller Macrolepidoptera were not identified.

Figure 18.–Suction trap, with 4-vaned baffle assembly and four 15-w. BL lamps, used in 1952 Texas pink bollworm attraction tests. Trap with 100-w. mercury vapor lamp is on pole at left.

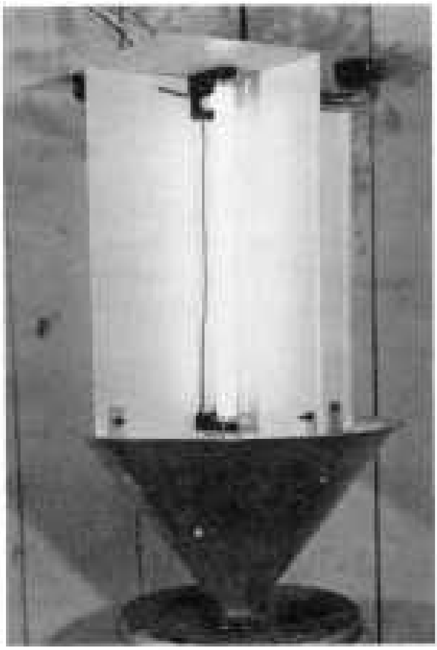


Figure 19.–Smaller trap designed in 1952 by Hollingsworth in Tex. Design is similar to suction trap shown in figure 18, without killing jar.

Data from the year's operation of the trap at Weslaco showed that Lepidoptera were active throughout the year in the Lower Rio Grande Valley of Texas. Large collections of the cabbage looper, *Trichoplusia ni* (Hubner), were taken every month and moths of the corn earworm were also collected every month as well as those of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith). This evidence of the general attractiveness of near ultraviolet radiation to many night-flying insects focused attention on the possible value of this trap design for general insect survey purposes.

Omnidirectional Trap

Changes in design of the electric insect trap with the vertically mounted BL lamps were developed from study of its performance and suitability in trapping insects. These changes included use of a larger metal collection chamber to replace the fruit jar, incorporation of a drain device in the funnel to remove collected water before it entered the collection chamber, and omission of a roof to permit upward as well as lateral light distribution.

Following these changes, the unidirectional and funnel-shaped mercury vapor traps developed in Indiana were compared directly with the omnidirectional trap (fig. 20) developed in Texas. The omnidirectional trap shown at the left is equipped with three 2-w. argon glow lamps. A second identical trap shown at the right was equipped with a single 15-w. BL lamp mounted vertically.

Results of the comparisons in 1955 by Hollingsworth and Carter (unpublished) showed that the omnidirectional trap with one 15-w. BL lamp collected the greatest number of pink bollworm moths and all other insects. The mercury vapor trap (with 100-w. mv. lamp) caught second largest number of all insects and the same number of pink bollworm moths as the unidirectional trap. The omnidirectional trap, with three 2-w. argon glow lamps mounted vertically, caught the second largest number of pink bollworm moths and least of all insects, an indication of selectivity for the pink bollworm. The unidirectional trap, with one 15-w. BL lamp mounted horizontally, ranked third in total insects collected but caught as many pink bollworm moths as the mercury vapor trap.

A commercial electric insect survey trap, similar in design to the omnidirectional trap with 15-w. BL lamp used in the preceding test, was announced late in 1955 and was mentioned by Taylor and others (*1956*). Before the availability of this trap, experimental electric insect traps had been installed at various locations to detect the appearance and abundance of specific insects, such as the European corn borer, the tobacco and tomato

Figure 20.–Omnidirectional light trap, developed in Texas about 1954, with three 2-w. argon glow lamps (left); and trap with one 15-w. BL lamp (right).

hornworm moths, and the pink bollworm. In 1952, for example, electric traps were installed along the Atlantic seaboard at 13 locations in 8 States to detect hornworm moths. In the Midwest, electric traps were installed in several States to locate infestations of the European corn borer. In 1953, such traps were operated in a number of cotton-growing States to check on the spread of the pink bollworm. In 1955, more than 60 electric insect survey traps were operated in 17 States.

Publication of Light Trap Survey Collections

As a public service the Plant Protection Programs, Animal and Plant Health Inspection Service,[7] U.S. Department of Agriculture, issues a weekly Cooperative Economic Insect Report (CEIR). It contains information supplied by cooperating State, Federal, and industrial entomologists and other agricultural workers.

Electric light trap catches of economically important insects were published in a few instances as early as 1952 in the CEIR. A special section on light trap collections of nine species of insects was initiated in 1955 and has continued since that time. In 1963, the number of insect species included in the report was increased from nine to 20, all Lepidoptera. Detection of other insects collected in light traps are also listed in other sections of the report.

Insect traps utilizing BL lamps rapidly became valuable tools to entomologists and others in determining the time of appearance and the seasonal abundance of important insect pest species (Pfrimmer (*1955 and 1957*), Stanley and Dominick (*1958*), Oatman (*1957*), Tashiro and Tuttle (*1959*), and Smith (*1962*)). However, several different kinds of BL traps were then being employed in general insect pest surveys in the United States.

Development of BL Trap Standards

The above situation led to action, in 1964, by the Committee on Insect Surveys and Losses, Eastern Branch, Entomological Society of America (E.S.A.), that resulted in the development of BL trap standards. A questionnaire was sent to 53 survey and extension entomologists, agricultural engineers, and plant pest control people known to be actively engaged or knowledgeable in insect light-trapping research or service programs for States and USDA.

Thirty-six questionnaires were returned to the committee, and 21 of them indicated that general insect survey BL traps should be standardized. Thirteen individuals recommended either a particular kind of trap or trap components as a standard.

A study of the returned questionnaires indicated that a definite majority used or recommended as a standard a light trap equipped with one linear 15-w.

[7]Formerly Plant Protection Division, Agricultural Research Service.

fluorescent BL lamp. Concerning trap components other than lamps, a majority reported or recommended the use of an omnidirectional trap with baffles, no fan, and a collection funnel opening (top) with a 10- to 18-inch diameter. No majorities favored or emphasized one size of collection container or one killing agent over others used. A few who listed ethyl acetate were enthusiastic about its use over cyanide. Several individuals thought that the position and location of the trap in the surveyed area is as important as the type of trap used.

The Committee reviewed the questionnaires and the literature on insect light traps, and gave particular attention to the results of recent investigations. This was done to help select a trap or trap components which would be durable, efficient, and low cost. On the basis of these reviews, the Committee proposed that certain trap design standards be used in general insect survey work. The design should include: One 15-w. BL lamp; omnidirectional design; baffles; no fan; 10- to 18-inch funnel opening (top diameter); and a collection container larger than 1-quart. For specifications of the trap dimensions and standards as well as pertinent additional recommendations, see figure 21.

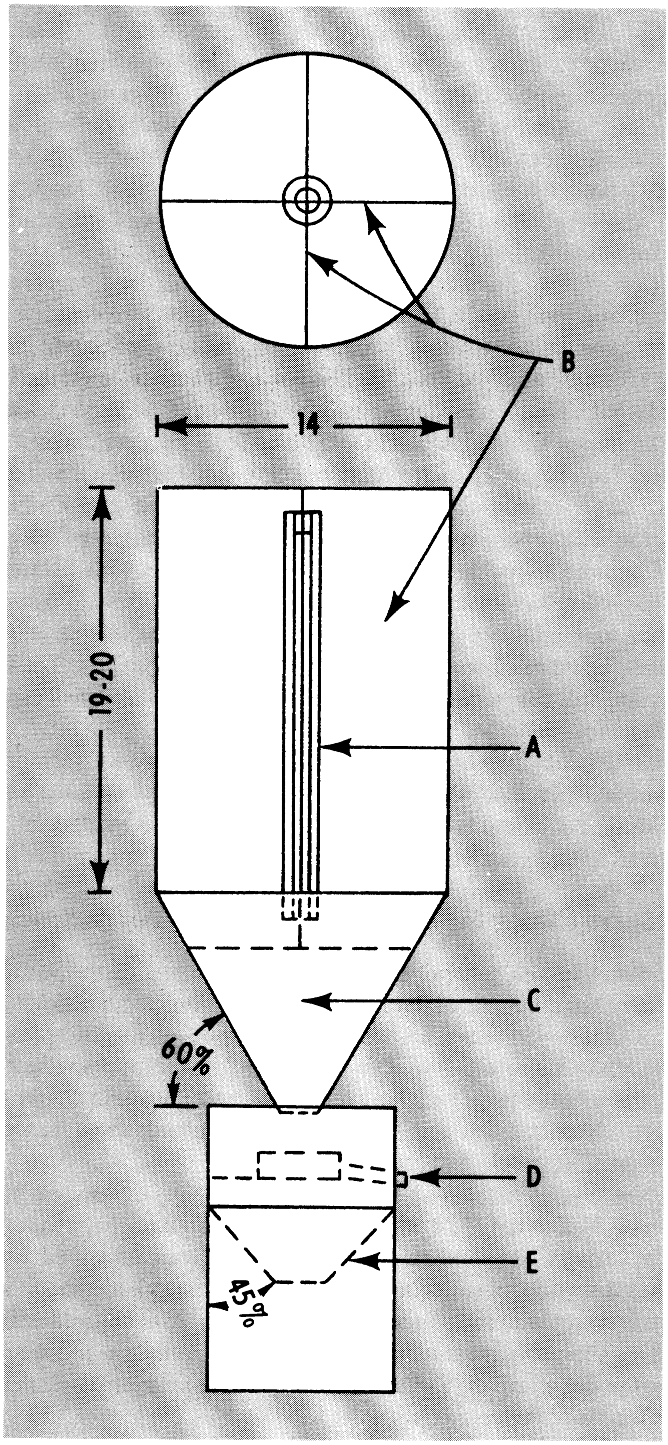
The Committee emphasized that its chief concern is with BL traps that are used in general insect-survey programs to determine the time of occurrence and abundance of established insect pest species, such as the corn earworm, fall armyworm, European corn borer, cabbage looper, and others. The Committee fully recognized the separate need for survey traps designed especially for detection or for research.

A general insect survey trap that meets fully the above specifications has been manufactured commercially for several years. The trap is used extensively in the United States and to a considerable degree abroad by Federal, State, and other research organizations.

Survey Traps for Individual Insect Families or Species

In contrast to the general insect survey trap, many of the various electric insect survey traps have been developed, at least initially, for a single species or, at most, a family of insects. Included in this group of specialized survey traps are: New Jersey mosquito trap; CDC miniature light trap; cigarette beetle trap; Asiatic garden beetle trap; pink bollworm trap; and European chafer trap. They have been described in part by Frost (*1952*) and more extensively by Hollingsworth, Hartsock, and Stanley (*1963*).

The New Jersey mosquito trap (fig. 11, p. 21), developed by Headlee (*1932*) and Mulhern (*1934* and *1942*), is a standard trap widely used in mosquito surveys. An American model of this trap described by Mulhern (*1953*) has a slightly larger tube and fan than the standard model, and is also being used in some areas of the United States. A 25-w. incandescent lamp is specified as the attractant in both standard and American models. Specifications for the design of the Department of Defense mosquito light traps[8] parallel those for the New Jersey trap.


B
14
19-20
A
C
60%
D
E
45%

Standards:

1. Attractant—one F15T8/BL lamp (15-watt black light) mounted vertically. See A.
2. Position of lamp—bottom even with rim of funnel, lower lampholder below rim.
3. Four baffles (two crossed), dimensions: total width 14″; total height above funnel rim 19″–20″; clearance between inner edge and lamp ¼″–½″. See B.
4. Funnel—slope 60°; top diameter 14″ (approx. ¾ length of lamp); bottom opening diameter 2″; lower end inserted into top of collection container ¼″ to form drip rim for water. See C.
5. No large canopy over top of baffles (such a cover reduces catches of some species).

Additional Recommendations:

1. Wiring system showing Underwriters' Laboratories (UL) seal of approval.
2. Electrical components mounted either on side or top, but if on top the area of obstruction to light not to exceed a 5″ square (25 sq. in.).
3. Use of a side-emptying drain placed in cover of collection can to leave collection container unobstructed. See D. Pan diameter at least 4″, depth 1″, drain opening ½″ × 1″ minimum.
4. Collection container designed for use of less harzardous killing agents, such as ethyl acetate (as compared to calcium cyanide) through use of insert funnel with sealing gasket, 45° slope and 2″ opening. See E.
5. Material—26 gauge galvanized steel minimum.

Figure 21.—Blacklight trap standards for general insect surveys.

Investigations on factors affecting the efficiency of light traps (American model New Jersey mosquito trap) for collecting mosquitoes (Barr and others *1960* and *1963*) indicated the following results: (1) Lighted traps caught more mosquitoes than unlighted traps, although the latter caught substantial numbers of Culex but not Aedes mosquitoes; (2) the heat produced by a 25-w. light bulb did not result in higher catches than when a cold (nonenergized) bulb was used; (3) trap color had little effect on the catch; (4) air movement by the fan also had little effect on the catch, although the range of air movements studied was not great; and (5) the catch was directly related to intensity of the light source.

Reed and others (*1935*) developed a suction-type electric insect survey trap for collecting cigarette beetles. The early work of Runner (*1917*) in establishing the greater attractiveness of blue or violet light as compared with orange or red was also mentioned. Further research by Tenhet in 1955 (unpublished) determined "that blacklight was appreciably more attractive to the cigarette beetle than any other light tested." Results of this work are reflected in current recommendations in Agricultural Handbook No. 233[9] that "these traps should be equipped with BL fluorescent tubes of more than 30-w. capacity." This trap is shown in figure 12, page 22.

An experimental, vertical suction-type light trap and a standard horizontal trap were compared in performance tests by Tenhet in 1954 (unpublished). No significant difference in the effectiveness of the two types of traps was noted. However, Parkhe and Kurup (*1959*) found that a vertical suction light trap with baffle plates, one lamp, and one fan has given about three to four times greater catch (of cigarette beetles) than the ordinarily used horizontal suction light trap.

Development of two Asiatic garden beetle traps was accomplished by Hallock (*1936*). Designs of both the small (figure 14, p. 24) and large traps, described by him, and the general survey trap are similar in the use of four baffles, funnel, no top cover, and location of the lamp attractant at the junction of the baffles. The larger trap was field tested in 1934 with four different lamps and in 1935 with seven different lamps. The G-5 lamp, a 100-w. mercury vapor lamp radiating 6.04 microwatts per sq. cm. at 1 meter distance in the near ultraviolet (BL) region, attracted approximately 60 percent more beetles in both years than a 500-w. daylight incandescent lamp, the next most effective attractant lamp.

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[8]Military specifications prepared by the Corps of Engineers, U.S. Army, Department of Defense.

[9]U.S. Department of Agriculture, Agricultural Research Service. Stored-tobacco insects, biology and control. AH No. 233, 43 pp. Revised September 1971.

The attractance of near ultraviolet radiation for the Asiatic garden beetle is further evidenced by detection of the pest in general survey traps for new county records in two Pennsylvania counties in 1969. Thus, the general survey trap is replacing the original Hallock design for detecting this insect pest.

The pink bollworm survey trap is of essentially the same design as the general purpose survey trap previously described. A special feature is that it is equipped with three 2-w. argon glow lamps or a 15-w. BL lamp as shown in figure 20. The principal radiation from the argon glow lamps, like that of the BL fluorescent lamps, is concentrated in the near ultraviolet region of the spectrum. Lamps of this type and wattage are nearly as effective as BL fluorescent lamps for attracting the pink bollworm moth, but are much less attractive to insects in general, particularly large moths and beetles. In a mixed collection, this helps to reduce damage to the rather delicate pink bollworm moths that must be in near perfect condition for positive identifications.

This trap is easily adapted to portable power sources because the power required for operating the lamps is low (6 watts). A portable power supply (fig. 22), developed by Hollingsworth and Briggs (*1960*), utilizes an automative-type battery as the basic power source. The conventional 115-volt, 60-cycle a.c. service is used when readily available, see figure 20, page 31. The trap has been used extensively in Arizona and California for pink bollworm detection and survey work (Berry and others *1959*).

Figure 22.—Pink bollworm survey trap with portable power supply.

Adults of the European chafer, *Amphimallon majalis* (Razoumowsky), were strongly attracted to radiation from fluorescent BL lamps tested by Tashiro and Tuttle (*1959*). When exposed to very low populations late in the 1958 season, traps containing these lamps captured up to 70 times as many beetles as the most attractive, chemically baited traps.

Studies of factors involved in the design and development of an effective survey trap for the European chafer were conducted by Tashiro, Hartsock, and Rohwer (*1967*) during the period 1959-63. A survey trap developed for the European chafer beetle in shown in figure 23. Special features of the trap include (1) a screen-bottomed collection container to hold the beetles alive and permit escape of small insects, (2) a rather flat funnel angle with a small, 3/4-inch opening which permits large moths to crawl out of the trap; and (3) a special wiring circuit which permits operation of the lamp either from conventional 110-volt, 60-cycle a.c. power or from d.c. batteries by the use of a special inverter. The parts are especially designed for compact shipment and easy assembly in the field. A smaller, similarly designed trap with a 6-w. lamp has been developed for battery operation in isolated locations. This trap is suitable for either European chafer surveys or general insect population surveys.

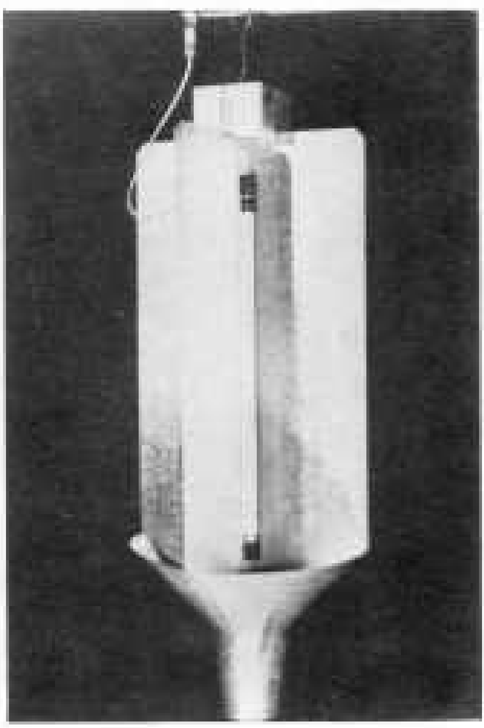

Figure 23.—European chafer beetle survey trap.

ELECTRIC INSECT TRAP STUDIES ON ECONOMIC SPECIES

The material presented has been concerned with a history of insect attraction to light in general, a description of various lamps and their spectral distribution, and a review of trap types that have been developed for use with electric lamps. The following material lists results of various investigations of electromagnetic radiation sources and traps that have been employed for the detection and control of a number of economic insect species.

European Corn Borer Survey and Control

Jablonouski (*1920*) reported an observation made by L. Baross, Bankut, Hungary, in which 50 to 80 percent of the Lepidoptera captured at acetylene light traps from June 17 to July 28, 1904, were European corn borer moths. The exact number of moths captured and the proportion of sexes were not recorded.

European Corn Borer Attraction to Light and Effects of Trap Design on Moth Capture

Caffrey and Worthley (*1927*) have indicated that repeated observations in New England with various types and colors of lights failed to show that European corn borer moths were attracted to artificial lights to any extent, even though the observations were carried on in fields where the moths were numerous and in their seasonal period of greatest activity. Gasoline and kerosene lanterns, acetylene lights, and electric lights of white, yellow, blue, green, red, and violet were used in these experiments. From the comparative number of moths captured at the different colored lights, a slight preference for white and yellow lights was shown. The proportion of captured males usually was greater than that of the females.

Kelsheimer (*1935*) conducted field and laboratory research to determine the influence of different colors of lights on the behavior of the European corn borer moth. He concluded that, when the filters were arranged in the apparatus in the ascending or descending order of wavelength and the light intensity transmitted through the filters was, in all instances, uniform or comparable the moths responded in significantly greater numbers to the lights of short wavelength than to those of long wavelength. The blue light of the series attracted more moths than did the red light on the opposite end of the series.

The flight of European corn borer moths to electric light traps was studied under field and laboratory conditions by Ficht and Hienton (*1939* and *1941*) and Ficht and others (*1940*). They found, as did Hervey and Palm (*1935*), that European corn borer moths may be captured readily in electric traps.

The 250-w. Mazda CX lamp used in the field tests for 1939 and 1940 by Ficht and others was manufactured with a special glass bulb which transmitted most of the ultraviolet radiation emitted by the tungsten filament. A second lamp, the 100-w. mercury vapor lamp H-4, was found to be more attractive to European corn borer moths than the 250-w. Mazda CX in subsequent laboratory and field studies. The distribution of power output from this lamp is shown in figure 5, p. 11. Power radiated by the 100-w. H-4 lamp was more than 10 times greater in the ultraviolet (280-380 nm) region than the 250-w. mazda CX lamp, 78 percent more in the visible violet-blue (380-500 nm) region, and 6 percent less in the green-yellow (500-600 nm) region.

In field tests, Ficht and Anderson (*1942*) compared European corn borer moth catches using six lamps of each type. The 250-w. CX lamps captured 19,107 moths or 53.6 percent of the total as compared with 16,487 moths or 46.4 percent of the total attracted by the 100-w. H-4 lamps. These results significantly showed that the predominantly ultraviolet, visible violet, and blue radiation from the H-4 lamps was approximately twice as effective in attracting the moths as was the energy radiated by the CX lamps when compared on a wattage basis. Female moth catch with the CX lamps was 53.9 percent of the total as compared with 56.4 percent by the H-4 lamps.

Results of field tests and laboratory studies combined indicated that the greatest radiation attraction to the European corn borer moths was in the range of 320-500 nm. Moths had shown no preference for lamps radiating energy at wavelengths shorter than 320 nm in laboratory tests reported by Ficht and Hienton (*1941*). However, in further laboratory studies, Ficht and Anderson (unpublished) compared the entire radiation from the H-4 lamp with that in the near ultraviolet (BL) (320-380 nm) region and found that there was a definite attraction to the moths for this relatively narrow wavelength region.

Taylor and Deay (*1950*) concluded from laboratory studies made in 1948 that the maximum attractiveness for the European corn borer moths at the intensity levels studied was in the near ultraviolet region. Thus, their studies confirmed those of Ficht and his associates that were completed just before Ficht's death in July 1941.

The early evidence of the attraction of European corn borer moths to radiation in the visible range, 380-760 nm, led Taylor and Deay to compare moth catches by lamps radiating energy primarily in the visible with other lamps radiating energy chiefly in the near ultraviolet. Unpublished data obtained by them during 1953-55 show that the 360 BL lamps attracted from 1.3 to 9.5 times as many such moths, on a wattage basis, as the incandescent lamps.

Further evidence of the greater attraction of black light as compared with visible radiation is found in a 7-year record (1958 to 1964) obtained by Altman and Brindley (unpublished) in Iowa. They compared two 15-w. 360 BL lamps, mounted horizontally, with a 200-w. incandescent clear lamp in modified Minnesota-type traps of very similar design (figs. 24 and 25) for attracting European corn borer moths.

Figure 24.—Modified Minnesota-type trap with two 15-w. BL lamps.

The 360 BL lamps and trap caught 2.33 times as many moths as the trap with incandescent lamp on a lamp wattage basis. During the same period an omnidirectional trap with one 15-w. 360 BL lamp, similar to the trap in figure 20, caught 29,755 moths while a trap, similar to that shown in figure 25, with 200-w. incandescent clear lamp caught 27,218 moths. On a wattage basis, the BL lamp and trap caught 10.4 times as many moths as the incandescent lamp and trap, but a part of the difference was probably due to variation in trap design. In the latter study 58.4 percent of the moths attracted by the BL lamp were females and 45.2 percent of those attracted by the incandescent lamp were females.

Ficht and Hienton (*1941*) showed that as the level of visible radiation was increased from 250 to 2,000 ft.-c., the catches of European corn borer moths increased at about the same rate as the increase in illumination. However, Taylor and Deay (*1950*) found that increasing the amount of near ultraviolet radiation increased the attraction of moths but not in direct proportion to the increase in radiant energy. In a comparative study of 250-, 500-, and 1,000-w. sizes of mercury vapor lamps, the 250-w. lamp was reported best on the basis of the number of moths caught per lamp-watt. From related studies, Beaty and others (*1951*) commented that 2,000-w. mercury vapor lamps attracted many moths but no satisfactory method was found for destroying the moths so concentrated. Adjacent traps with lamps of smaller wattage failed to compete with the 2,000-w. lamp in attracting moths.

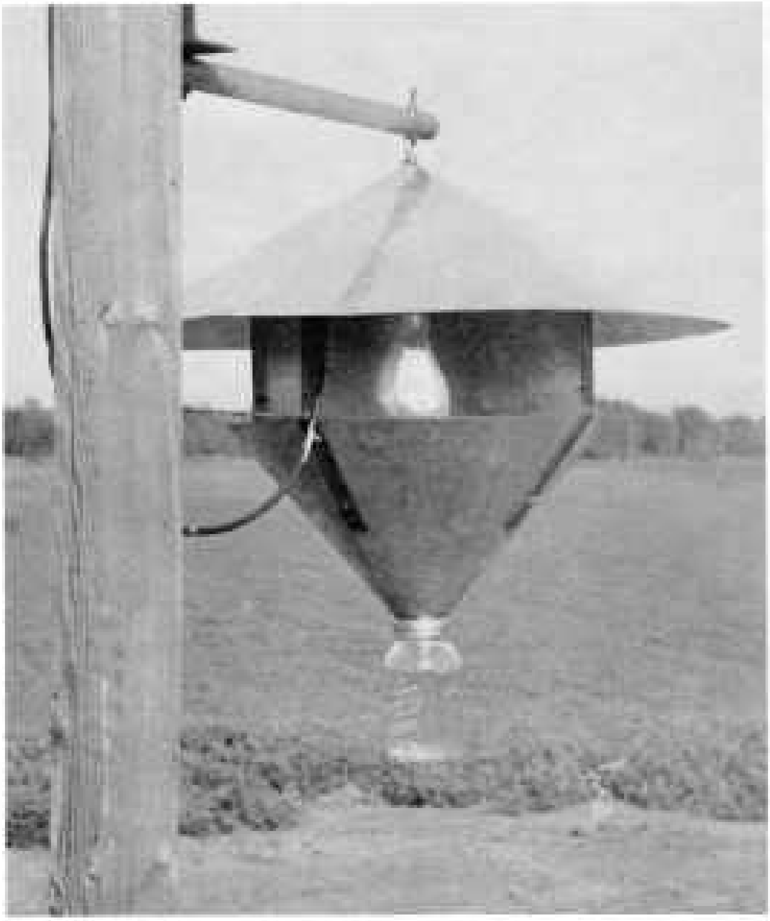

Figure 25.—Modified Minnesota-type trap with 200-w. incandescent lamp.

Corn Borer Survey Activities With Light Traps

Bogush (*1936*) reported that a trap with a 500-w. light was of great value in detecting the presence of insects when only present in small numbers. In 1930, the first year of the trap installation at Bairam-Ali, Turkmenistan, Central Asia, the European corn borer was detected for the first time, although the Entomological Organization had been in existence there for more than 10 years.

Stirrett (*1938*) reported that the European corn borer flight to light traps showed that males are attracted to the light in larger numbers than are the females, while the females are more strongly attracted to corn than are the males. He found no apparent correlation between the numbers caught in the light trap and those observed in the field on individual nights. However, he concluded that the light trap is a better measure than any individual cornfield for determining seasonal limits of flight within the region.

Apple (*1962*) reported the operation during the previous 4 years, of an omnidirectional insect trap with two 15-w. BL fluorescent lamps at one location to provide information on the occurrence and abundance of certain nocturnal flying insects. European corn borer moths responded well to this light attraction, and satisfactory numbers were taken to support a study on the relationship between adult flights and subsequent larval numbers in late planted sweet corn.

The use of electric light traps to assist in the prediction of European corn borer outbreaks and the timing of insecticidal applications is well established. The European corn borer was added to the Economic Insect Report in 1963 when the list of economically important insect species collected in light traps was increased from 9 to 20.

Corn Borer Control Activities With Light Traps

Hervey and Palm (*1935*) reported an attempt to control the European corn borer in sweet corn fields with electric light traps. Six circular grid traps, equipped with 75-w., type A. Mazda lamps, were operated in each of two fields of sweet corn from June 11 to August 8, 1935. Totals of 488 female and 367 male moths were captured in a little over 2 acres of corn. It was concluded that the type of light traps used has little value in controlling the borer in the field.

Ficht and Hienton (*1941*) found that infestations and populations could be greatly reduced but not eliminated by lighting cornfields with one 250-w. Mazda CX lamp and circular grid trap per acre. In 1939, reductions of corn borer infestation in a 10-acre cornfield by use of electric light traps averaged 75.3 percent below those in three adjacent fields. Also in 1940, reductions in a 12-acre lighted field, averaged 66.7 percent below those in five adjacent fields. Adult corn borer catch per trap averaged 1,117 moths per season in 1939 and 3,218 in 1940. In 1938, examinations for sex showed that predominance of females over males in light trap captures was 65.5 percent females and 34.5 percent males and, in 1939, 60.6 percent females and 39.4 percent males. Practically all female moths taken at light traps in these experiments were gravid, and not more than one percent were spent.

Deay and Foster (*1944*) reported experiments that were designed to determine the effect of electrocutor light traps on the European corn borer infestation and population in double-cross hybrid field corn in 1943. They found that one trap with a 100-w., H-4 mercury vapor lamp per acre reduced the infestation of first generation corn borers in corn planted June 1 from 27.5 to 14 percent; one light per acre reduced the fall population of borers from 3.6 to 2.5 borers per plant in corn planted June 1 and from 4.3 to 2.6 borers per plant in corn planted June 8—the fall population being all second generation borers.

Reduction in corn borer infestation by use of light traps has been found possible as indicated. However, field tests have not been made in sufficient magnitude with suitable equipment to determine whether economical control can be accomplished by light traps.

Codling Moth Survey and Control

Recognition of the attraction of light to the codling moth more than a century ago is evidenced from a statement by Glover (*1865*)—"Bonfires in June evenings are recommended for the moth (codling)." However, other entomologists held different opinions. Slingerland (*1902*) stated that "codling moths are not attracted to lights and only rarely may one accidentally fall a victim; the highest record this far is eight codling moths in 15 nights." A similar reaction was indicated by Newcomer and others (*1931*).

Codling Moth Attraction to Light and Effects of Trap Design on Moth Capture

Light Attraction.—One of the earliest recorded experiments on the attractant value of various colors of light to the codling moth was made in New Mexico in 1915, 1916, and 1917 by Fite as reported by Eyer (*1937*). Nine incandescent lamps used each of the 3 years in an orchard were suspended over tubs of water which served to trap the moths. While only commercial types of tungsten filament lamps were used and the various colors incorporated in the globes presented equal emission of light, "the superiority of a blue or purple (violet) light over other colors was well demonstrated."

Laboratory investigations on the response of the Oriental fruit moth and codling moth to colored lights were conducted by Peterson and Haeussler (*1928*) during the 3-year period 1925-27. They used clear incandescent lamps combined with several color screens as attractants. Their studies showed that, if codling moths are given a choice of lights varying in color from red to violet and the relative intensities of the colored lights are approximately equal, practically all of the moths will go to blue and violet lights. Few or no adults are attracted by red light. So far as observed the response of males and females to colored lights appeared to be similar.

Results of tests conducted by Yothers (*1928*) in a closed fruit storage room in 1926 in which codling moths were emerging and in an orchard in 1926 and 1927 showed evidence of positive attraction of light to the adult codling moth. In the closed storage adult moths were readily attracted to a small light. In 1927, they were attracted in large numbers under normal orchard conditions to varying intensities of light in water-pan and electrocuting types of light traps.

Parrott (*1927*) also conducted experiments on the attraction of codling moths to light in storage houses and in orchards during 1927. The results were more favorable in cold storage houses than under field conditions where 10 different incandescent lamps were used in six traps during the season. He reported that several species including the codling moth "were negatively phototropic where colors at the red end of the visible were used, that their response was more positive at the violet end." In subsequent work in 1934, Parrott and Collins (*1935*) used 75-w. Mazda lamps, 60-w. Mazda CX lamps, sunlamps, and mercury vapor tubes, "all of which proved attractive to the codling moth."

Collins (*1934*) found that temporary morphological changes in the compound eyes of the codling moth took place under the impact of light, and that these changes were correlated with changes in the behavior of the moths. Inferring that the most attractive spectral bands to the codling moth might lie in the near ultraviolet, violet, and blue regions, Collins and Machado (*1935*) studied the pigment migration induced by radiation of those wavelengths. Their studies indicated that: (1) "of two light sources having the same continuous spectrum, the more brilliant source elicits the more rapid iris-pigment migration and is the more attractive; (2) of two light sources which have unequal spectral ranges, the one including the bands which evoke the more rapid iris-pigment migration, even though its visual intensity and relative energy are less, is more attractive."

Studies were made in an apple orchard, a fruit-packing house, and in a laboratory by Marshall and Hienton (*1935*) during 1933 and 1934 on the attraction of adult codling moths to a wide variety of lamps radiating energy in the visible and ultraviolet regions. Their early results indicated the most attractive region of the spectrum was that between 3,000 and 4,000 A, or near ultraviolet and violet. A 15-w. mercury vapor tube attracted more moths in the orchard than Mazda C, Mazda CX, and special G-1 lamps of greater wattage. Codling moths were attracted to any electric lamp in a three-story, 72- by 72-foot packinghouse enclosed with a cloth screen. In the packinghouse darkened during the day and with an electrocuting light trap operating both day and night, more than 98 percent of the emerging moths were attracted and killed (Davis, *1935*). The maximum catch for a single day was 15,579 adult codling moths; and the total for the season, up to July 27—the end of the first brood emergence-was 236,300 moths.

From their investigations which continued through 1937, primarily in the laboratory, Marshall and Hienton concluded (*1938*) that there are three things which influence the attractiveness of light to the codling moth: intrinsic brilliance (luminous flux); the size of the luminous area; and the color. Small amounts of ultraviolet, in addition to blue and violet seemed to have little attraction to this moth. Large amounts of ultraviolet, based comparatively on the lamps used in the tests, added to the attractiveness of the lamp. This was particularly true of the special H-3 lamps (modified H-4). A dark blue, 200-w. tungsten filament lamp showed the greatest attractiveness of all lamps tested, when all other conditions were equal.

Comparative tests made in 1933 on the attraction of adult codling moths to inside-frosted incandescent lamps in 40-, 100-, and 200-w. sizes were reported by Eyer (*1937*). He concluded that the clear yellowish-white light developed by this type of globe was increasingly attractive up to 200-w. capacity. In 1935 and 1936, his further tests with mercury vapor tubes, sun-lamps, and an incandescent lamp, showed that, of the various light sources tested, the mercury vapor types proved most attractive. This type produced 300 to 700 lumens in the visible region within wavelengths of 300 to 700 nm, that is, largely blue violet and ultraviolet in quality.

In comparing the relative attractiveness of blue, green, amber, red, and white incandescent lamps in electrocutor traps to the codling moth during 1934 and 1935, Bourne (*1936*) found that codling moth showed a preference for the blue lamp.

Another attractant being used experimentally in traps for male codling moths is the laboratory-reared virgin female of the species. When compared with light traps, the sex lure or pheromone traps captured more moths in the early season, but from midseason to later season this pattern was reversed (Madsen, *1967*). He also reported that in 1966, studies to test the effectiveness of the pheromone traps as a means of control, using one trap per tree, did not result in fewer infested fruit than in the control trees, even though large numbers of male codling moths were captured. Much is yet to be learned about the future value of the codling moth pheromone trap whether used alone or possibly in combination with light traps for survey, control, or both, of native codling moth populations.

Light trap design.–Eyer (*1937*) mentioned that traps used by Fite consisted of lamps suspended over a tub partly filled with water. Parrott (*1927*) used traps in which a shallow, broad pan collected insects below the lamp. Parrott and Collins (*1935*) later used the electrocuting type exclusively in their experiments. Bourne (*1936*) improved the water-pan trap but found the electrocuting-type superior to the improved unit. Herms and Ellsworth (*1934*), Marshall and Hienton (*1935*) Patterson (*1936*), and Hamilton and Steiner (*1939*) used the electrocuting-grid type of trap.

In his work initiated in 1933, Eyer (*1937*) used only grid-type traps but compared the Akins suction-type gnat trap (fig. 10, p. 19) with two electrocuting grid-type traps for a 44-day period in 1936. He reported that electrified grids and suction fan retrieving devices were about equally effective for capturing moths attracted to lights.

Electric light traps and bait traps, operated alone and in combination, were studied by Worthley and Nicholas (*1937*) to develop a trap of effectiveness equal to but cheaper than the cylindrical electrocuting type used by Parrott and Collins and others. In their 1934-36 investigations, Worthley and Nicholas compared the codling moth catches in four types of traps as follows: (1) A 75-w. Mazda lamp in (a) an unpainted trapping globe described by Tietz (*1936*) (b) globe painted black at top and bottom, and (c) globe painted to give light only through slots; (2) a 75-w. Mazda lamp over 12-inch-diameter bait pans; (3) a 6-inch can with bait but without reflector or light; and (4) a 75-w. Mazda lamp enclosed by electrocuting grid.

Results reported on this work showed that the effectiveness of bait traps may be greatly increased by suspending them beneath 75-w. lights. This combination of lamp and reflector suspended above molasses-water bait in a 12-inch diameter pan appeared to be more effective than the electrocuting light trap. The trapping light globes were found to be less effective, and the electrocuting grid type to be most effective with light alone as the attractant. Comparisons between the electrocuting trap and other devices may be misleading because many of the electrocuted insects are burned beyond recognition. For that reason, this type of trap is seldom used for survey purposes.

Van de Pol (*1956*) reported that in a series of observations at Doetinchem, Netherlands, in 1955, the codling moth species seemed to react more strongly to a 125-w. ultraviolet lamp than to a 125-w. lamp which radiated light visible to the human eye. Van de Pol and associates used a Robinson-type electric trap that they had modified by increasing its height and decreasing its diameter. They developed a grid light trap at Wageningen that had a more general effect than the Rothamsted and Robinson traps but it was considered too dangerous for practical application.

In 1960, Baggiolini and Stahl (*1965*) developed Changins, a new model light trap, a design somewhat similar to the Minnesota-type trap, equipped with a mercury vapor lamp. Starting with the original Robinson trap, they rearranged the position of the lamp in relation to the collecting tube and placed the lamp base up instead of down. They also included a device for collecting the captured insects in a jar. In 1961, the new trap was compared directly with an early model Robinson trap at three locations in France. The number of codling moths caught with the Changins trap was generally more abundant or at least equal to the reference trap. Also, the attracting power of this trap model, like the majority of other traps, extended to a large number of species of different orders.

Effects of Temperature and Wind Velocity

The number of codling moths captured by light traps is affected by several factors besides the attractant lamp and trap design. Under optimum conditions of light intensity for moth attraction that exist before and after dark, the temperature and wind or air-movement may reduce the number of moths captured.

Collins and Nixon (*1930*), Borden (*1931*), Eyer (*1937*), and Patterson (*1936*) are in general agreement that the flight of codling moths is definitely inhibited at temperatures below 60° F. Borden (*1931*) found that one of the most notable factors controlling flight in the field is the starting of a breeze or wind. Just the faintest air movement over the tree tops effectively cut down the flight. When a wind was blowing very few, if any, moths were observed, even though the temperature and light intensities were favorable.

Pristavka (*1969*) reported on the effects of temperature and wind velocity which are assumed to be the leading factors affecting the quantity of catches of the codling moth. Results of calculations made show that in the sum-total of all factors the effect of wind velocity makes up 12 percent and the effect of temperature makes up 20 percent.

Codling Moth Survey Activities With Light Traps

Hamilton and Steiner (*1939*) examined light trap captures at half-hour intervals on several different days during 1934 and 1935. They found that lamps did not begin to capture codling moths much before light receded to 0.2 ft.-c. or less. Although moths came to traps all hours from late dusk to early dawn, 85 percent entered the traps before 10:30 p.m. and peak captures occurred between 7:30 and 9:30 p.m. The authors found that light traps artificially stimulate moth activity after it normally ceases in the evening or before it begins at dawn. Bait traps, however, capture moths during periods of normal flight activity at dusk and dawn. Thus, light trap captures are better indicators of moth abundance than bait traps but provide less information about the amount of normal moth activity.

Groves (*1955*) compared bait and light traps for catching codling moths in 1951 and 1952 using a Robinson trap (fig. 26) equipped with an 80-w. mercury vapor lamp. The single light trap caught considerably more codling moths than the 12 bait traps in 1951 and the 10 bait traps in 1952 with which it was compared.

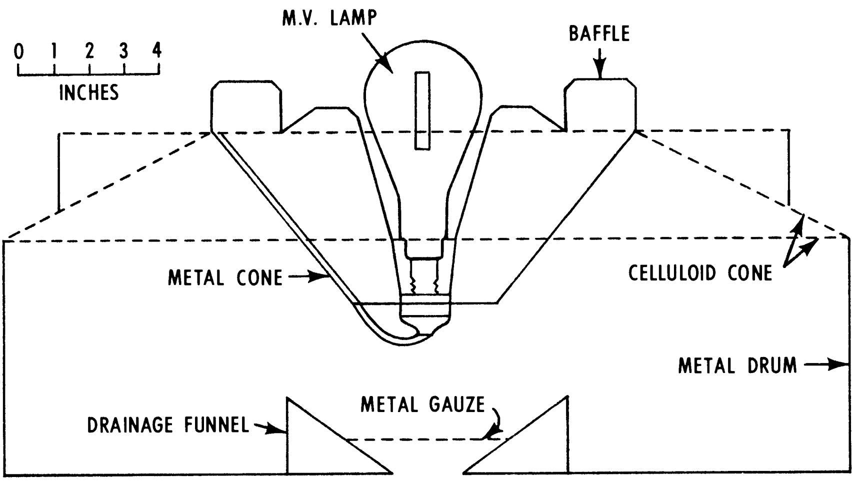

Figure 26.–Cross section of the Robinson insect trap.

Russ (*1960*) observed codling moth occurrences in 1958 and 1959, using a further improved Robinson light trap, for organizing a warning service in Austria. The improvements in the light trap tended to provide greater safety. Of the improved types, 52 were in use in 1960 to provide information needed for control purposes.

Oatman and Brooks (*1961*) reported that results of 5 years' experience (1956-60) with BL traps, similar in design to the omnidirectional trap pictured in figure 20 on page 31, had shown that it is an effective, additional survey tool for orchard insect populations. The BL trap had also proved to be several times more effective than the regular type incandescent light trap for surveying insect populations, Oatman (*1957*). Its greatest value had been to time spray applications for the individual pests, especially the second generation codling moth.

In 1961, Madsen and Sandborn (*1962*) found that a funnel-type trap with a 15-w. BL lamp was very efficient in trapping codling moths. In a study on mating and oviposition behavior of the codling moth, Gehring and Madsen (*1963*) compared BL trap catches with that of standard diamalt bait traps. They concluded that the BL trap gave a more precise determination of codling moth activity and would, therefore, aid in the scheduling of control measures for application at the most effective time. Further, a light trap, particularly BL, is a very effective codling moth lure, and a single light trap will substitute for a number of bait traps. Their work confirmed Geier's (*1960*) in which the light trap was more effective than the bait-pans in drawing significantly younger females from the field population.

Barnes, Wargo, and Baldwin (*1965*) tested and reported a new low-wattage ultraviolet light trap for detecting codling moth activity (fig. 27.) The trap consists of a 10-inch funnel with a single, 10-inch-square sheet metal baffle mounted over it. The funnel neck is removed and a jar lid is soldered on for attaching a 1-quart jar. The lamp is a 4-w. fluorescent ultraviolet unit designated as blacklight blue (BLB). The dark purple glass filters out nearly all visible light. The lamp is placed horizontally within the funnel and just below the edge, directing most of the light upward. Because of the direction of radiation, the trap should be hung in the lower half of the tree. The advantage of this trap with the low-wattage lamp is the reduction in total number of moths captured with resultant easy sorting to record codling moths.

In Germany, Mesch (*1965*) made studies in 1962 and 1963 to improve the results of light traps used in connection with a warning service against codling moths. He found a slightly modified form of the Minnesota light trap to be the most suitable for the purpose. Mercury vapor lamps of types HQA 125-w. and HQL 250-w. were used in the light trap. Catches with HQL 250-w. lamp were larger and easier to evaluate. This trap was reported to be simpler to construct than the Robinson light trap, the New Jersey light trap, and the existing wood light trap of Steiner and Neuffer. Mesch commented that observations with light traps have become part of the forecasting and warning service.

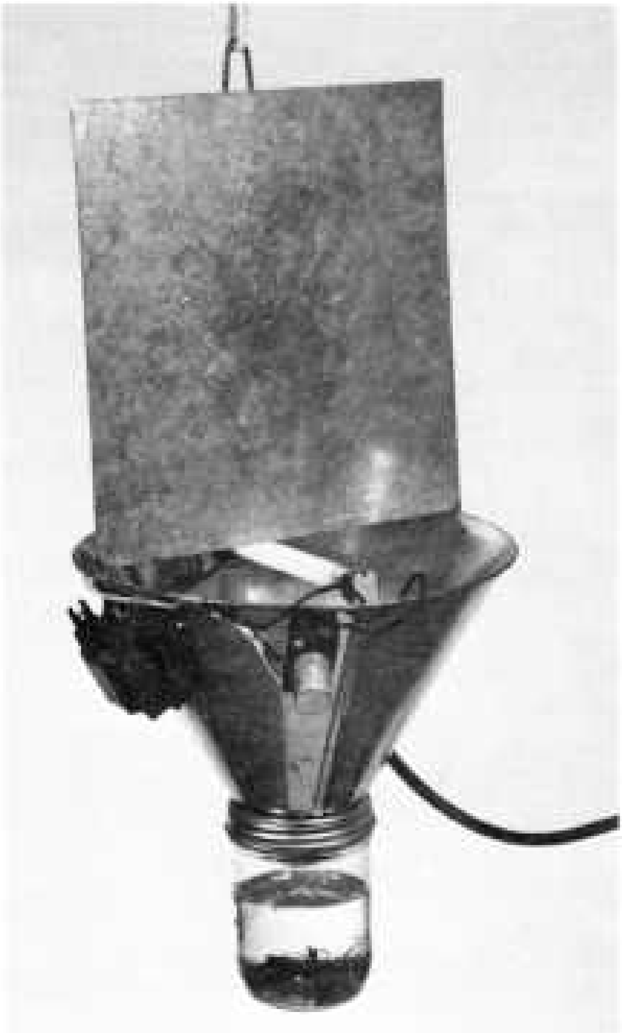

Figure 27.—Simplified low-wattage ultraviolet light trap for codling moth. (Courtesy of Entomology Department, University of California, Riverside.)

The codling moth was one of the species added to USDA's weekly Cooperative Economic Insect Report in 1963 when the number of insect species included in the list of those collected in light traps was increased from 9 to 20. Thus, there is international acceptance of the use of light traps as a determinant of codling moth activity.

Codling Moth Control Activities with Light Traps

In 1928, efforts to control the codling moth by using artificial light were undertaken by Herms (*1929*). Six 500-w. Mazda lamps were suspended directly over a block of 15 trees consisting of several apple varieties. He continued his studies on the same block in 1929 using eighteen 500-w. Mazda lamps (Herms, *1932*). Borden (*1931*) reported that even with the increased light intensity of the 1929 experiment, the artificial lights did not deter moth activities sufficiently to affect observations. When only the artificial light was present, light intensity readings about the trees were not more than 4 ft.-c., which is much less than the natural light intensity at sunset, the time of maximum flight. The first season (1928) showed a 31-percent reduction in fruit worminess, while the second season showed a 30-percent reduction.

In 1933, Herms and Ellsworth (*1934*) compared the use of traps with red, light-blue, and white lights to determine the effect of lamp color on apple worminess in the same orchard used in 1928 and 1929. Their results showed a considerable reduction in worminess under the light-blue lamp; this is, a worminess of 50.3 percent against 73.6 percent nonsprayed and nonilluminated, and 77.3 percent under the red and 74.2 percent under the white. Although the evidence pointed toward a considerable reduction in worminess under the blue, they did not recommend the use of the codling moth-blue (Monolite) traps as a substitute for sprays.

Headlee (*1932*) also undertook to determine whether control of codling moth could be secured by means of orchard lighting. He used Mazda C lamps to irradiate the foliage wall of the apple tree at a level of 10 ft.-c. during first brood activity and reduced fruit injury by that insect approximately 50 percent. He then used in succession Mazda CX, mercury vapor daylight, and 1000-w. Mazda C red-painted lamps. He noticed no particular difference in moth activity with the Mazda CX than with the Mazda C lamps. He reported that increasing the light energy from the violet end of the spectrum seemed to increase the normal oviposition activity of the codling moth. Increasing the light energy delivered from the red end of the spectrum seemed to induce largely abnormal activity. He also indicated that in all probability an irradiation of a little more than 30 ft.-c. would be necessary during favorable evenings and mornings to prevent the codling moth from ovipositing.

Collins and Machado (*1937*) made a 4-year study of the effects of light traps on a codling moth infestation. They used an electrocuting type light trap with a 75-w. Type A Mazda lamp in every apple tree in the lighted area (13 to 18 trees). Some mercury vapor tubes and sunlamps were used as attractants for comparison with the Mazda 75-w. lamp. Trees included in the experiment with light traps received no lead arsenate or from two to four lead arsenate cover sprays. Collins and Machado's data indicated that the light traps exerted sufficient influence on the codling moth infestation to reflect a measurable decrease in injury to the fruit. An evaluation of this influence, based on the different methods of comparison used, led to the following inference. Under the given experimental conditions, the control achieved by light traps was comparable to that achieved by applying two lead arsenate cover sprays.

Experiments on codling moth control by electric light traps were conducted in southern Indiana (1934-35) and in the Hudson Valley, N.Y., in 1936 by Hamilton and Steiner (*1939*). The light-trap experiments in Indiana were conducted in a 5 ¼-acre block of 30-year-old apple trees located near the center of the orchard. Within this block there were 175 trees available for use. In New York, the light trap area consisted of a four-by six-row block of mature trees, located near the center of a Baldwin apple orchard.

Circular grid type electric traps were used. In 1934, three types of lamps were used-G-l mercury vapor clear glass, Mazda 60-w. CX inside-frosted, and Mazda 60-w. clear. In 1935, the 60-w. CX lamp was discontinued and the following added: Mazda 150-w. clear, Mazda 300-w. clear, Mazda CX 250-w. inside-frosted, and a coiled mercury vapor tube. The G-1 and Mazda 60-w. clear lamps were each used in three-eighths of the trees, while the other six lamps were compared in the remaining trees. In 1936, the G-1 mercury vapor, mercury vapor tube, CX 250-w. frosted, and Mazda 200-w. clear were used in New York.

Comparative tests of the relative attractiveness of different lamp types indicated that the mercury vapor tube and the G-1 mercury vapor lamp were about equally attractive to codling moths and definitely superior to Mazda lamps of 200-w. or less. The results also showed that the lamps used were not powerful enough to attract moths much farther than 35 feet. In 1934, traps that were suspended over clear spans 35 feet from apple trees averaged only 5 moths per trap as compared with 127 moths per trap for those over apple trees. Codling moth infestation in the 5 ¼-acre, light-trap area (fig. 28) was reduced 44 percent below that in the surrounding check blocks. In 1935, seasonal conditions were extremely unfavorable for the codling moth, and the lighted area showed a 90-percent reduction in infestation.

In 1933, Patterson (*1936*) initiated a 4-year experiment, in Canada, on the value of electrocuting light traps. He used a cylindrical electric grid trap with a 75-w. Mazda lamp as attractant in every fourth tree in 1933, and increased the density to one trap per tree in a 6- by 10-tree block in 1934. The first two cover sprays of lead arsenate were applied to the lighted trees. The regular spray schedule of four cover applications was applied in 1933 and 1936 and five in 1934 and 1935 to the unlighted trees. The sprayed blocks showed 20.9, 38.8, and 9.1 percent more damaged apples in 1934, 1935, and 1936, respectively, than the lighted blocks. The crops were extremely small during these years, and these conditions may have produced exceptional results.

Eyer (*1937*) reported that although the fruits in illuminated trees were often less wormy than those in neighboring unsprayed trees, the benefit was not sufficiently pronounced to warrant the recommendation of light trapping as a substitute for spraying.

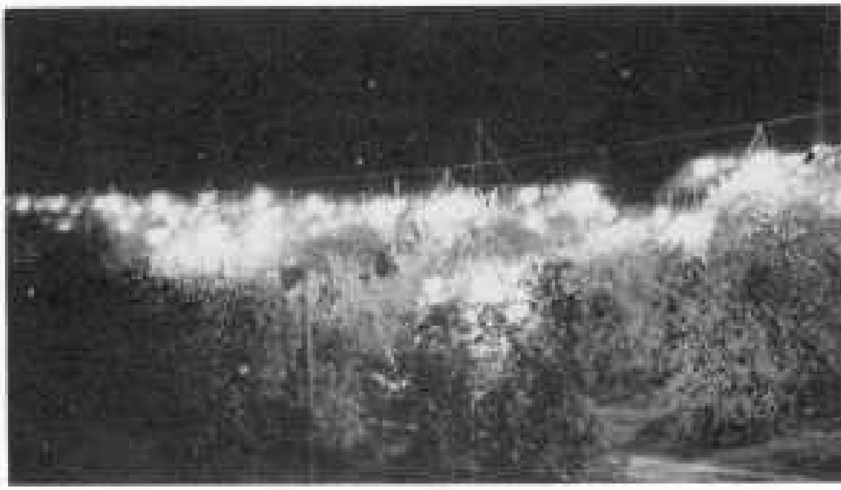

Figure 28.–Electric insect traps in operation at Indiana orchard during 1934 experiment on codling moth control.

Despite the early evidence of a possible reduction in the number of spray applications through use of light traps, there has been no recent large experiment for attempting to control codling moths with light traps alone or in combination with a spray program.

Tobacco Hornworm and Tomato Hornworm Survey and Control

Turner (*1920*) recorded the capture of eight tomato hornworm moths in an electric light trap in 1918. He used a 300-candlepower arc lamp as the attractant and is among the first to indicate the attractiveness of light to that insect.

Martin and Houser (*1941*) reported tobacco hornworm moth catches, during 1938 and 1939, in which 10 incandescent, mercury vapor, and fluorescent lamps were used in two types of traps. A 1,000-w. mercury vapor lamp was more attractive than three 1,000-w. incandescent lamps operated in one trap.

Hornworm Moth Attraction to Light and Effects of Trap Design on Moth Capture

The attraction of adult tomato and tobacco hornworms to near ultraviolet radiation between 320 and 380 nm was reported by Deay and Taylor (*1950*). They studied the attraction of hornworm moths to radiant energy from three groups of five 15-w. fluorescent lamps, each mounted vertically on electric panel grid traps. The attractant lamps used were germicidal, blacklight, and blue with maximum radiation at 253.7 nm, 365 nm, and 440 nm, respectively. Of the three types of lamps used in 1948, the 360 BL lamp was outstanding in attracting 92.6 percent of both species of hornworm moths captured by traps in open fields. Taylor and Deay (unpublished) found that a funnel-shaped trap (see fig. 17, p. 28) caught a greater percentage of hornworm moths attracted by the lamp than did the electrocutor grid type because these large moths did not pass between the grid wires. In many cases, the moths were only temporarily stunned, then recovered and flew away.

Brown (unpublished) designed, built, and tested the V-shaped collecting container (fig. 29) for an electric grid trap to capture attracted hornworm moths in 1949. Moths, when stunned, dropped into the trough immediately below the grid, thence through a baffled tube into a wire basket from which they could not escape. Initially, the grid wire spacing was seven-sixteenths of an inch, but this proved to be too close and was increased later in the season to five-eighths of an inch with a resulting increase in moth catch. The trap was equipped with two 30-w. BL lamps mounted vertically and caught 2,712 moths of both sexes during 1949.

Stanley (*1965*) reported that further tests made by Brown in 1950, with 5/8-inch and larger grid spacings showed grid trap performance less satisfactory than that of a new unidirectional trap designed by Brown (fig. 30). A fluorescent painted baffle, irradiated by two 40-w. BL lamps mounted horizontally, replaced the grid. This design was based on observations that had revealed a tendency of the moths to stop on white walls adjacent to traps before finally going into the traps.

In 1951, commercial model of this new unidirectional gravity-type trap was compared with a suction-type trap and a grid trap for attracting and capturing hornworm moths at Tifton, Ga., by Girardeau, Stanley, and LaHue (*1952*). They operated four of the new type traps (fig. 31) (equipped with two horizontally mounted 30-w. BL lamps in each) in addition to an experimental suction-type trap (with four 15-w. BL lamps and a 1/6-hp. motor-driven 16-inch diameter fan), and a grid trap (with four 19-square-inch grids and four 300-w. incandescent lamps). The gravity-type and suction-type traps, each with a total of 60 watts in BL lamp capacity, attracted and captured from 596 to 1,143 tobacco hornworm moths during April 22 through August 25. The grid trap with 1,200 watts in incandescent lamps caught only five such moths and practically no other hornworm moths. The average catch of the four gravity traps was 856 moths. The suction trap caught 916 moths. Results of this test gave further evidence that much greater numbers of hornworm moths were attracted to near ultraviolet than to visible radiation.

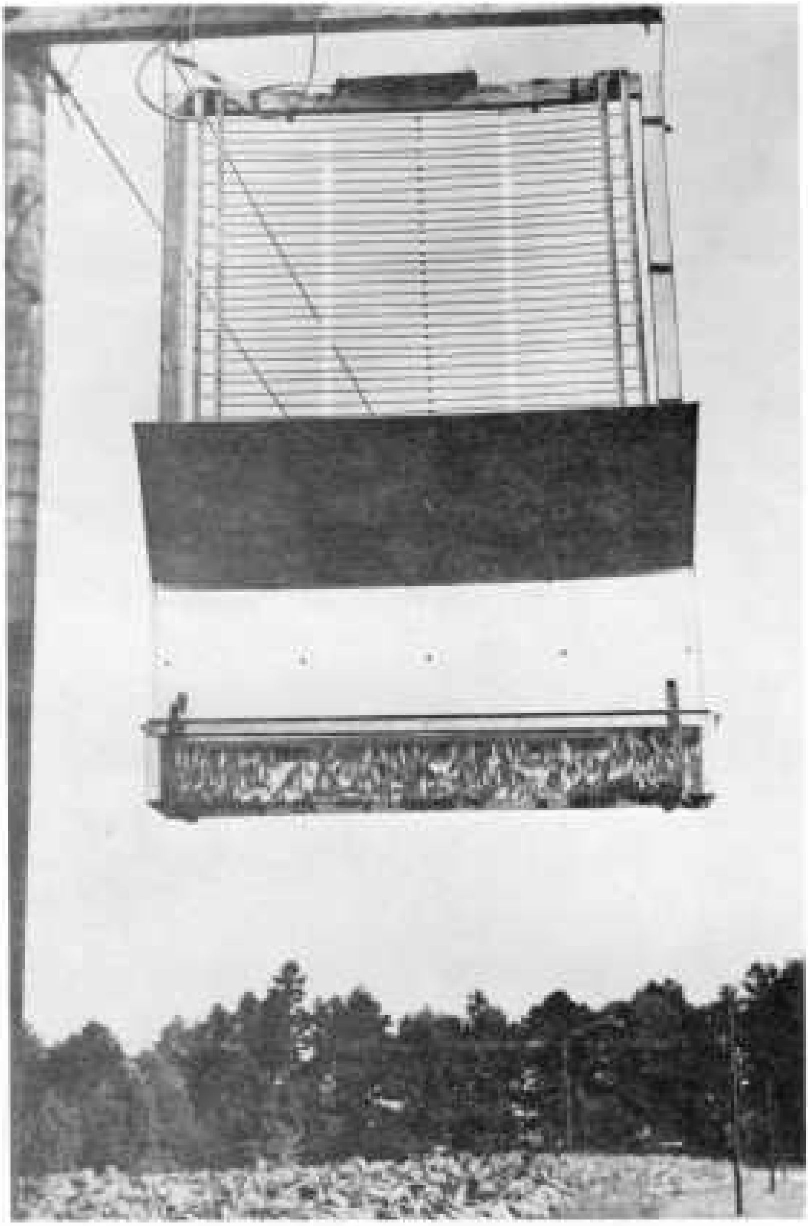

Figure 29.–Electric grid trap with collection device for capturing hornworm moths after striking grid.

In 1953, Taylor and Deay (unpublished) also compared the gravity-type and suction-type traps that were used at Tifton, in 1951, with an 18- by 18-inch electric grid trap. In their comparisons, each of these traps was equipped with a total of 60-watts BL lamp capacity. While the number of moths caught was much smaller than that at Tifton, the suction-type and gravity-type traps were about equal and caught decidedly more moths than the grid trap.

Further comparisons of near ultraviolet and visible radiation as attractants for hornworm moths were made in 1954 and 1955 by Taylor and Deay

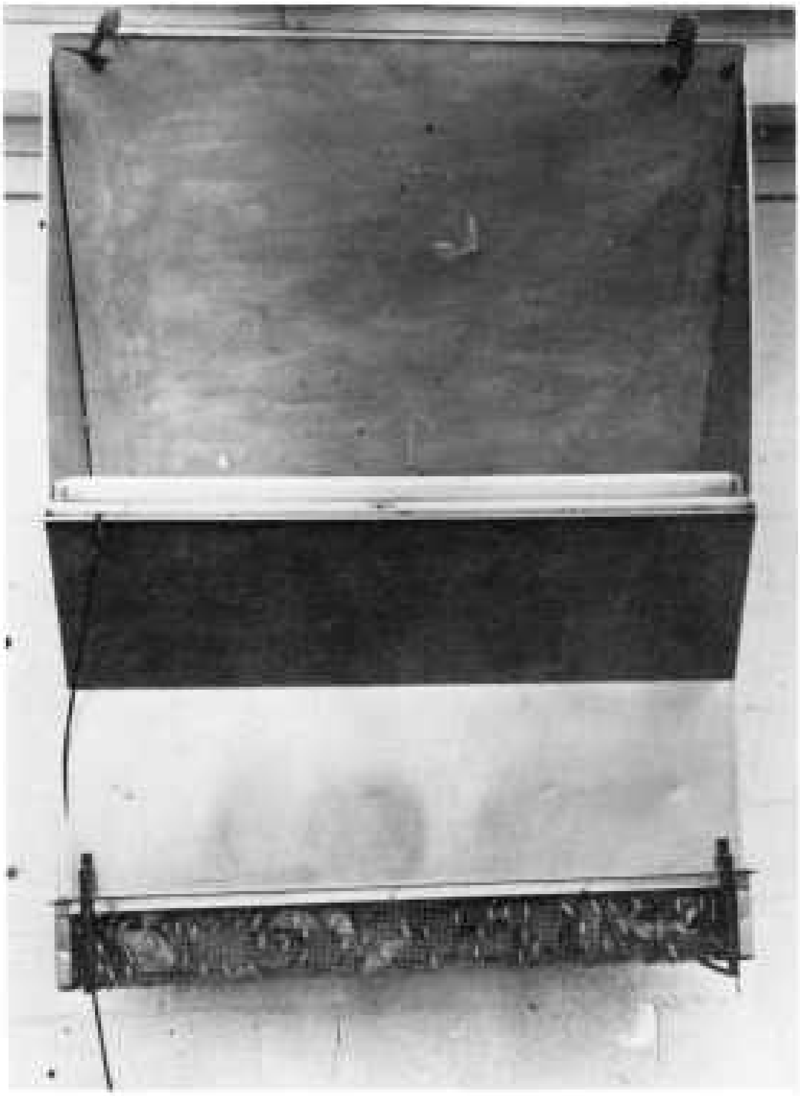

Figure 30.—Gravity-type electric insect trap with two 40-w. BL lamps.

(unpublished). Identical unidirectional gravity traps, one equipped with a 15-w. BL and the other with a 75-w. incandescent lamp, caught 402 and six hornworm moths, respectively, during a 102-day field test in 1954. In a parallel 51-day field test in 1955 with omnidirectional gravity traps, one trap with a 15-w. BL lamp caught 210 hornworm moths while another with a 200-w. incandescent lamp caught only two moths. These results further emphasized

Figure 31.–Commercial model of unidirectional hornworm light trap, developed in 1950 in North Carolina.

the greater attraction of near ultraviolet than visible radiation to hornworm moths.

The omnidirectional trap used in 1955 was developed by Taylor and used during the 1956-59 seasons in Indiana experiments to protect tobacco from tobacco and tomato hornworms, as reported by Deay (*1961*). This trap (fig. 32) included a single, vertical, 15-w. BL lamp mounted in a single vertical baffle. The baffle was mounted virtually within a funnel, the baffle extending an inch above the funnel discharge opening to a height of 19 inches above the funnel rim. The funnel was 14 inches in diameter at the top, 2 inches in diameter at the bottom, and 12 inches high. The collection chamber or can was made of 9-inch-diameter metal furnace pipe, 24 inches long, and held against the funnel by spring tension. On one end of this furnace pipe, a flange was turned inward to hold a bottom made of 1/4-inch-mesh hardware cloth. The traps were supported between 8-foot steel fence posts as shown. A trap of similar design with the attractant lamp mounted horizontally caught fewer hornworm moths than the trap described with the lamp mounted vertically.

Bell (*1955*) studied 21 commercially available electric lamps which radiate energy in parts of the spectrum from the ultraviolet through the infrared as attractants for moths of the tomato and tobacco hornworm species. He concluded that five of the lamps, with high radiation outputs between 320 and 400 nm, were more attractive than those which did not radiate a significant amount of energy in this range. He also determined that the same lamps are most attractive to both species and that the response was about equal for males and females of each species.

Figure 32.–Omnidirectional light trap with one 15-w. BL lamp, developed and used in Indiana for capturing hornworm moths.

Kent (*1958*) and Raju (*1959*), seeking to determine a specific wavelength of radiant energy of greatest attraction to hornworm moths, irradiated them with monochromatic energy of approximately 10-nm bandwidth in the spectral region 320 to 380 nm. They used a kymograph to record the movements of the insects, but this necessitated impaling the test moths on a wire suspension mount. On the basis of their studies, the age and sex of the moth, the wavelength and intensity of radiation, and the atmospheric conditions did not significantly affect the moths' reaction to radiant energy in the 320 to 380 nm (near ultraviolet) region as tested.

Pruitt (*1960*) continued investigations on hornworm attractions in the same range of wavelengths and developed equipment suitable for subjecting the moths to ultraviolet irradiation that would eliminate the necessity for piercing them. This was accomplished by placing the moths in cells (1 by 1 by 3 inches) and observing them individually with the aid of an infrared telescope. He also did not find any single narrow waveband (10 nm wide) significantly more attractive to the moths than other wavebands, in the 300 to 380 nm region.

Menear (*1961*) and Lam (*1964*) conducted further experiments on responses of hornworm moths to radiation in the visible as well as in the ultraviolet region in a light-tight, air-conditioned chamber. They used a commercial monochromator as the radiation source to replace the modified spectrograph used by Kent (*1958*), Raju (*1959*), and Pruitt (*1960*), and thus secured better control of the source.

Menear (*1961*) found that the aggregate reaction of 531 individually tested moths was greatest at 315 nm when compared with responses at bands spaced 20 nm apart within the range of 315 to 455 nm. Further, he found that responses were nearly as good throughout the ultraviolet region as at 315 nm.

Lam (*1964*) irradiated 848 tobacco and tomato hornworm moths individually with energy bands having a half-width of approximtely 10 nm centered at 312.9, 334.1, 365.4, 404.7, 435.8, 491.6, 546.1, and 578 nm. A significant difference in response to waveband treatments was found in each moth group based on sex, species, and source (trapped or reared). Generally, the responses were greater for the shorter wavelengths by both field-caught and laboratory-reared hornworm moths. However, no single wavelength having an extremely light stimulative efficiency for hornworm moths was discovered.

Hoffman, Lawson, and Peace (*1966*) reported experiments in 1964 in which they placed from one to 30 virgin female moths of the tobacco hornworm in individual BL insect traps to determine the effects of combining these two attractants. They found that for each additional virgin female, up to 10, placed with the light trap, the male catch increased by a factor equal to the male catch of the trap without virgin females. They also indicated that males coming to light traps did not seek out the virgin females, but reacted primarily to the blacklight, suggesting that at close range the radiation is a stronger attractant than the virgin females.

Cylindrical cages, 3½ inches in diameter by 6½ inches long and made of wire screen with 14 by 18 mesh per inch, confined the females and prevented mating. The cylinders could be attached to or removed from the traps easily (fig. 33) or be hung at different distances from the trap sites. The cages were used extensively in later efforts to achieve hornworm population control in North Carolina and St. Croix, V.I.

Hornworm Survey Activities With Light Traps

Morgan and Lyon (*1928*) found that amyl salicylate was attractive to hornworms, and they developed methods of using this bait to trap the moths. The traps developed were designed to offer both olfactory and visual attraction to the moths.

Entomologists and engineers of USDA and several State agricultural experiment stations recorded tobacco and tomato hornworm moth captured during the 3-year period, 1952-54, at 13 locations in Florida, North Carolina, South Carolina, Tennessee, Virginia, Maryland, New Jersey, and Connecticut. The captures were made with the improved omnidirectional type of BL trap (fig. 34), developed by O. A. Brown.[10]

Large numbers of hornworm moths (more than 1,000 per season) were captured particularly at seven locations in Florida, North Carolina, South Carolina, and Tennessee, according to Stanley (unpublished). A much larger percentage of tomato hornworm moths taken were females (41 to 45 percent) than was observed for the tobacco hornworm species (25 to 28 percent). Information from earlier studies indicated that the males and females of both species of hornworm moths occur in nearly equal numbers in the field.

In 1955, the Cooperative Economic Insect Report (mentioned on p. 32) included a special section on light trap collections of certain insects. Since that time, the section has included data on both the tobacco and tomato hornworm species and has provided a continuous survey record at many locations in the United States.

Hornworm Control Activities With Light Traps

Stahl (*1954*) tested bait and electric light traps as possible aids in the control of hornworms on tobacco by capturing the moths. He reported that "field studies indicated that the use of either bait or light traps had little effect on the abundance of and damage caused by hornworm larvae on tobacco at or near the traps."

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[10]Deceased (formerly with Agricultural Research Service, U.S. Department of Agriculture, Oxford, N.C.).

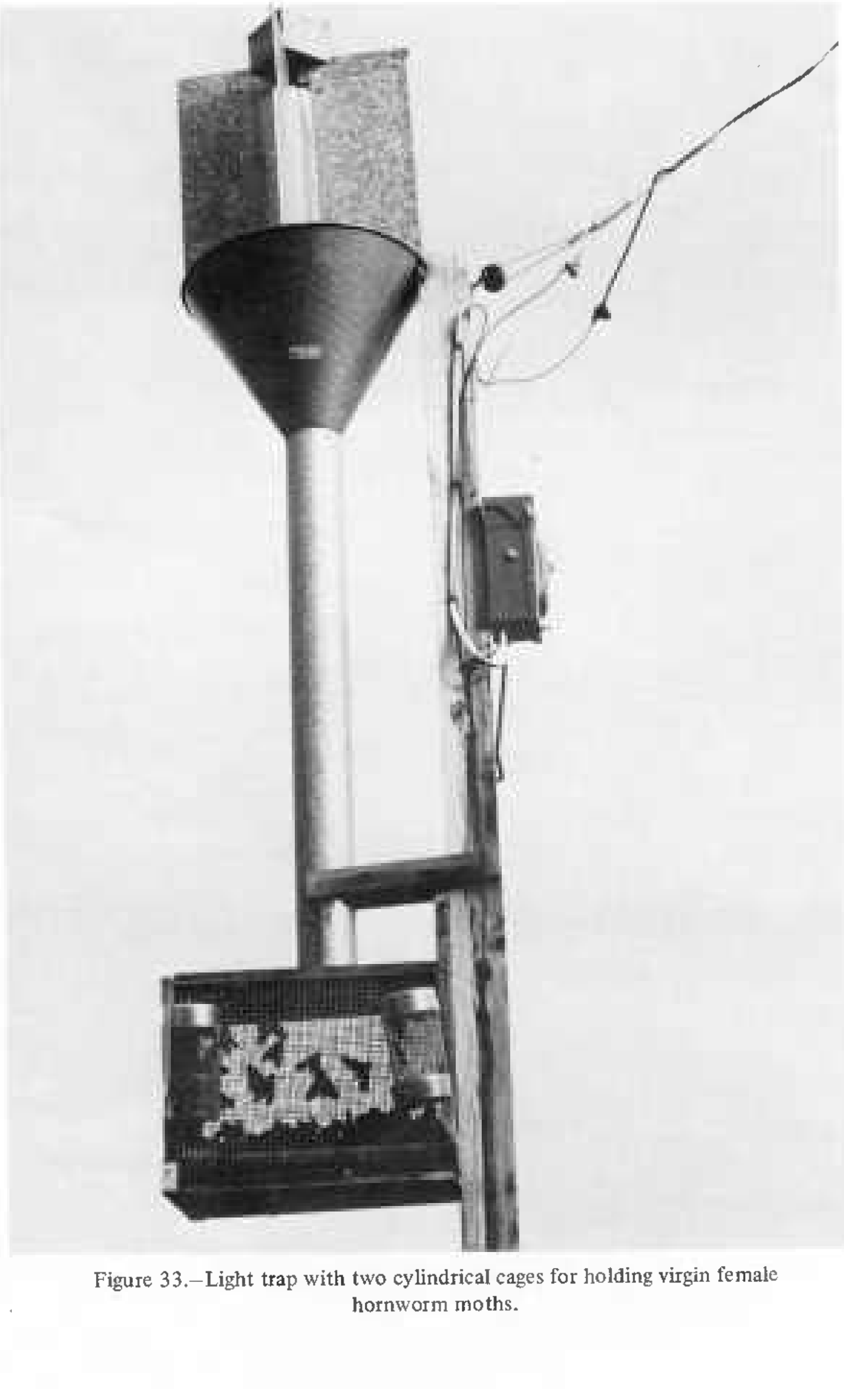

Figure 33.—Light trap with two cylindrical cages for holding virgin female hornworm moths.

Stanley and Dominick (*1958*) experimented with gravity- and suction-type light traps (figs. 34 and 35) during 3 years 1954-56, to determine the responses of the tobacco hornworm and tomato hornworm moths to blacklight radiation in the field and to evaluate these traps as a means of controlling hornworms. At each of three locations, three traps of the same type were placed in a 5-acre tobacco field. Suction-type traps were used at one location and gravity-type traps at the other two. Each trap was equipped with BL lamps of 60-w. total capacity. While no heavy infestation occurred during the 3 years, the nine traps

Figure 34.–Gravity-type omnidirectional light trap with two 30-w. BL lamps designed particularly for hornworm moth capture.

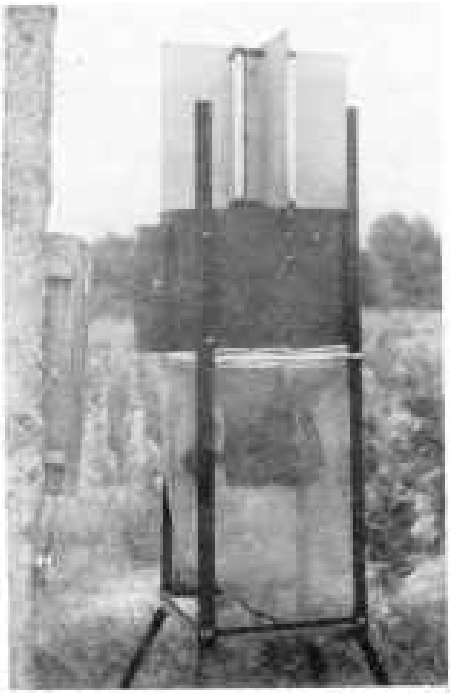

Figure 35.—Suction-type omnidirectional light trap with four 15-w. BL lamps mounted vertically.

caught 9,653 hornworm moths in 1954, 21,571 in 1955, and 24,002 in 1956; 50.5, 45.7, and 22.4 percent, respectively, were of the tobacco hornworm species. At one location in 1956, where the heaviest infestation of the 3-year period occurred, tobacco plant damage from hornworms was reduced 16 percent by the use of light traps.

Experiments were conducted in six tobacco fields in Indiana during the 1956-59 seasons by Deay (*1961*) and Taylor. Fourteen to 17 of the traps developed by Taylor, (fig. 32, p. 58) were used at these tobacco fields to attract and capture hornworm moths. Preliminary experiments in 1954 and 1955 indicated that a trap equipped with one 15-w. BL lamp would protect the tobacco within a radius of 100 to 120 feet from the lamp. The number of lamps used per field varied with the size and shape of the field. Deay and Hartsock (*1960*) showed that, on an average, one trap equipped with one 15-w. BL lamp decreased the number of infested plants by 73.5 percent and the amount of leaves eaten by 77.4 percent in an area 100 feet from the trap.

On the basis of these investigations the Departments of Entomology and Agricultural Engineering, Purdue University Agricultural Experiment Station, issued a mimeographed paper entitled "Directions for the Use of Light Traps to

Control Hornworms on Tobacco," in June 1961. These indicated that "Satisfactory control of tobacco hornworms on tobacco with the light trap[11] developed at Purdue University depends on three things: (1) The time of the year the traps are in operation, (2) the arrangement of the traps in the field, and (3) the height of the traps above the ground."

These early attempts to protect tobacco crops against hornworm damage were on a small-plot basis where only a few traps were placed in or around a field. The studies in Virginia were conducted in an area of more extensive tobacco production and of greater density than that in Indiana.

Lawson, Gentry, and Stanley (*1963*) initiated experiments in 1961 designed to use light and bait traps as a means of investigating the numbers, habits, and movements of hornworm moths and to test the possibility that such traps might be used to reduce populations in large areas. In experiments with bait traps and poisoned feeders, Scott and Milam (*1943*) indicated that these devices reduced the numbers of eggs laid by more than 50 percent when they were used on areas of 1 square mile or more.

Lawson and others (*1963*) in comparing catches made by three light traps and 34 bait traps showed that the mean light-trap catch of tobacco hornworm moths was 206 times greater than that of bait traps and about 36 times greater for the tomato hornworm species. Light-trap catches of male moths of both species were greater than for females, while catches of bait traps had a sex ratio near unity. The number captured by bait traps, however, was very low in comparison with light traps at all seasons and was zero during the early part of the season.

In other (*1961*) studies, these men showed that hornworm moths were strong fliers and capable of moving 3 or 4 miles in a single night. In that year, the greatest distance that hornworm moths were known to travel was 6.3 miles, but in 1962 this was increased to 8.2 miles. Thus, the moth flights into a small area under any control method could be heavy.

As a result, they designed and installed in 1962 a large-scale light trapping experiment in an area near Oxford, N.C. A circular area, 12-miles in diameter, was covered with about three light traps per square mile. These 324 traps were similar to the design which later was adopted as a standard for survey traps but with 18-inch funnel top width. The area trapped was increased to a 20-mile diameter circle in August 1964, with a total of about 1,100 light traps (Stanley and Taylor (*1965*)). The trap density was doubled in the inner 8-mile-diameter area to increase the catch of smaller tobacco insects such as the tobacco budworm *Heliothis virescens* (Fabricius), using a fan trap. This fan trap was identical to the gravity trap already in use, except for the 10-inch, 414-c.f.m., propeller fan, mounted in a vertical cylindrical section midway in the funnel (fig. 36).

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[11] Omnidirectional light trap with one 15-w. BL lamp developed and used in Indiana for capturing hornworm moths.

Figure 36.—Suction-type light trap with 10-inch propeller fan.

The general objective of the experiment has remained the same throughout the 1962-70 period--namely, the evaluation of the effect of light traps on insect populations inside the trapped area as compared with those outside the area. Lawson and others (*1963* and *1966*), Stanley and others (*1964* and *1965*), and Gentry and others (*1967*) reported results of these experiments for the years 1962-64. Lam and others (*1968*) reported for the years 1965-66. During 1962-66, the estimated hornworm reductions in the trapped area ranged from 54 to 94 percent, depending on the species, sex, and year.

During 1967-70, the number of traps in operation was varied to accommodate additional experiments such as the release of sterile male tobacco hornworm moths. Conclusions reached for this period were indicated by Lam and others (unpublished) that "Hornworm populations, although low throughout the locality, were suppressed within the test area during the years that traps were operated. When no traps were operated, hornworm populations inside were equal to or greater than they were outside the area. Stalk cutting and stilt bug populations may have aided in reducing hornworm populations, but a major portion of the reductions appeared to be caused by the presence of operating traps."

Lawson and others (*1963*) estimated that, because of the hornworm moths' movement capability, somewhat less than 5 percent of the hornworm moths inside a center circle of 1-mile radius would come from outside the 6-mile-radius, trapped area. Such movement into an experimental area could prevent a true evaluation of the trapping effect on the hornworm populations. To overcome this condition, St. Croix, V.I., was selected in 1965 as a suitably isolated island for conducting research where very little moth movement to and from the island could occur, since the island is 36 miles from the nearest land mass. A preliminary survey conducted with a single light trap in 1962 established the presence of hornworm moths on the 84-square-mile island.

The objective of the experiment on St. Croix was to determine the possibility of suppressing an isolated tobacco hornworm population by the use of electric insect traps. Initially, nine light traps of the type used in the Oxford, N.C., installation (fig. 33) were operated in widely separated locations over the island. The collections of those traps, from April 1965 to March 1966, were used as base-year data for comparison with later collections. On May 25, 1966, about 250 suction-type traps of the same size and design as those used in North Carolina (fig. 36) were placed in operation. They were distributed over the island as evenly as terrain permitted at an average density of three traps per square mile. Fifty-three of the traps were designated as survey traps and insects captured by these were collected regularly three times a week until July 1968, when biweekly collections were begun. Before moth capture was recorded, fans were removed from these traps to reduce damage that would increase difficulties of identification. Early in 1968, fans were removed from the remaining group of traps (about 200) because the gravity-type trap without the fan had been found as effective as the fan-type trap; this also eliminated the fan maintenance problem.

Increasing light trap collections of tobacco hornworm male moths by use of caged virgin females have been mentioned previously (Hoffman and others (*1966*). Use of virgin females to bait light traps on St. Croix was begun with 63 traps in March 1968. This use was increased to 123 traps in June and practiced on all of the traps from July 1968 to December 1969, excepting the original nine traps. Cantelo and others (*1972*) reported that the tobacco hornworm collections were reduced by light traps alone to 37 percent of those occurring before the 21-month period of mass trapping began. They also reported a further reduction to 14 percent of the original level during the period when virgin females were used as an added attractant, March 1968 through December 1969. The authors indicate that their results suggest that severe suppression of tobacco hornworm populations in the United States does appear to be a possibility if blacklight traps are used in sufficient density and maintained for several years.

Studies were made with light traps in two tobacco growing areas, about 100 square miles each in South Carolina and Kentucky during 1964-66. The 300 light traps in each community were farmer-owned and operated and were similar in size and shape to those used in North Carolina (fig. 33, p. 61). Hornworm populations, in South Carolina, as measured by field infestation counts on field tobacco and sucker growth, were approximately the same for the light-trap and outside areas for all 3 years of the experiment (Hays, *1968*). Poor trap construction and, in many cases, poor installation created serious maintenance problems which the owners could not readily correct, but this situation alone may not have produced the inadequate performance.

Results in Kentucky where trap construction and procedures for installation were better than in South Carolina, were more favorable. However, the reduction of hornworms and larvae within the trapped area was not great enough to achieve adequate control of tobacco and tomato hornworms in 3 years' use of BL traps, according to Jones and Thurston (*1970*).

Heliothis Zea (Corn Earworm, Cotton Bollworm, Tomato Fruitworm) Survey and Control

Riley (*1885*) cited an early instance of the response of this insect (*Heliothis zea*) to light thus: "Mr. Crane of Mandarin, Florida, who lost in 1878 a large proportion of his crop of tomatoes by *Heliothis*, in 1879 built fires of light wood in his field with much profit." He also mentions a simple trap-lantern used in Texas which "proved most effectual against the ravages of the bollworm, which in 1877 did more harm here than Aletia, and which was killed in great numbers by this method."

Despite this early apparent success, later use of oil lamps as attractants in light traps proved to be of little value. Howard (*1897*) and Quaintance and Brues (*1905*) reported unfavorable results. The latter indicated that "all observations serve to show that the attracting of moths to ordinary oil lights is an utterly hopeless task."

However, at about the same time, other observations were recorded of the bollworm moth's attraction to electric lamps. Morgan (*1897*) reported large numbers of this moth attracted to the vicinity of an electric lamp during the previous season. Chittenden (*1901*) also stated that during 1 week in late September 1,900 bollworm moths formed about 16 percent of the total number of moths attracted to the electric street lights at Washington, D.C. Cockerell (*1914*) also noted large numbers of moths around electric street lights in Boulder, Colo., about 90 percent of which were bollworm moths. He supposed that they were a migrating flight from the South. Stanley (*1932*) listed the bollworm moth among a number of noctuids caught at electric lamps on high buildings in Knoxville, Tenn., during 1931.

Moth Attraction to Light and Effects of Trap Design on Moth Capture

Ditman and Cory (*1933*) studied the responses of earworm moths to light transmitted by various filters in a 6- by 7- by 8-foot darkroom during 1932. Their investigations, although limited, showed that the moth reaction to radiation from various filters at the time of liberation changed after several hours. The filter that attracted most moths for the first hours would not attract the most moths after 3 or 4 hours. Initial responses were generally greatest to radiation in the violet-blue region.

Carruth and Kerr (*1937*) tested three types of light sources in electrocuting lantern traps against female corn earworm moths in cornfields during 1936, attempting to reduce larval infestations in sweet corn. Two types of mercury vapor lamps, one of 60 watts and the second of 25 watts, each attracted more corn earworm moths than did a 75-w. tungsten-filament lamp, although more males than females were caught. No appreciable reduction in larval infestation resulted from any of the traps used.

Walkden and Whelan (*1942*) reported on owlet moths taken at six light traps in Kansas and Nebraska during 1935-37. The data disclosed distribution, seasonal flight periods, and peaks of abundance of various species including the corn earworm. Incandescent lamps were used in all traps, two with 500-w. and four with 200-w. size in each. Insect catches were low early in the season, but increased markedly in the fall. Total trap catches per season varied widely from a low of 25 to a high of 2,186 moths. Forty-five percent of 3,149 moths examined were females.

Studies of corn earworm moths caught in 40 electric insect traps of two different styles, both of which used electric lamps as the lure, were made during 1937 at Clarkston, Ga., by the Georgia Experiment Station (*1938*). In one trap type, the moths were caught in a pan of kerosene suspended below the lamp; in the other type, insects flew into an electrocuting grid that surrounded the lamp. The average rate of moth catch per trap per day was almost identical for the season June 17 to August 12. However, in June when moths were most abundant, the electrocuting trap caught decidedly more than the kerosene trap, but the reverse was true the latter part of July and early August.

In 1938 and 1939, Martin and Houser (*1941*) compared the attractiveness of 10 incandescent, mercury vapor, and fluorescent lamps to the corn earworm moth in two types of traps. Each of the two types of traps consisted of three main parts—a low cone-shaped top, a hopper, and baffles—and differed in baffle arrangement. In 1938, three baffles were set equidistant with their edges at right angles to the lamp. In 1939, a half-cylinder vertical shield was extended more than halfway around the trap as a baffle. There were many nights when corn earworm moths did not come to the light traps. No moths came on 30 percent of the 78 nights that the traps were operated in 1938; none came on 22 percent of the 91 nights that they were operated in 1939. Many earworm moth individuals loitered about the light trap and rested on nearby objects before entering the traps. Also, flight habits of this moth indicated no sharp difference in response to any of a series of incandescent, fluorescent, and mercury vapor lamps. Further, the 100-w. H-4 and S-4 mercury vapor lamps were (with the exception of the June 1938 total) more attractive to earworm moths than the 100-w. and 150-w. tungsten lamps or a 15-w. blue fluorescent lamp. However, on an equivalent wattage basis, the blue fluorescent lamps would have radiated more total energy in the 320-380 nm (near ultraviolet) area than the S-4 or H-4 lamps and captured more moths.

Taylor and Deay (*1950*) reported on the attraction of the corn earworm moth in great numbers during 1948 to sources radiating considerable near ultraviolet energy.

Girardeau and others (*1952*) reported bollworm moth captures in six electric insect traps at Tifton, Ga., in 1951. Four of the traps were unidirectional, gravity-type with two 30-w. BL lamps mounted horizontally (fig. 31, p. 57). A suction-type trap, with 16-inch diameter, 1/6-hp. motor driven fan, and four 15-w. vertically mounted BL lamps similar to that shown in figure 18, was a fifth trap. The sixth trap was the electrocutor type with four 19-inch square grids and four 300-w. incandescent lamps. Capture of the bollworm moths was most effective with the suction trap in which 80 percent of the collection consisted of this species while all six traps were operated from March 25 to August 25. The suction trap catch for the entire period of operation (March 25 to October 20) totaled 17,198 moths. Sex counts, made on several series during the height of the flight period, indicated that equal numbers of males and females were taken. A suction trap, identical to that used at Tifton, was also operated in 1951 under test at College Station, Tex. for the period May 9 to October 9. Rainwater (unpublished) reported a total collection of 27,335 bollworm moths in that time.

Glick and Hollingsworth (*1955*) during 1953 at College Station, Tex., conducted laboratory and field investigations on the response of the cotton bollworm to certain ultraviolet and visible radiation. Fifty-six tests were made, including incandescent, mercury vapor, glow discharge, and fluorescent lamps (ultraviolet and visible) as attractants. The H100-SP-4 mercury vapor lamp with blacklight transmitting filter was found most attractive to the bollworm moth. However, a single 15-w. BL fluorescent lamp was rated the most efficient light source per watt of input for collecting bollworm moths in traps of the type tested. The trap used with all attractants (fig. 20, p. 31) was built to utilize from one to four lamps in the center of a three-vaned baffle assembly. The funnel was provided with a deflecting cone and drain device to prevent moisture from entering the 1-gallon cyanide collecting jar.

Deay, Barrett, and Hartsock (*1965*) reported results of extensive studies at Lafayette, Ind., on the flight response of the corn earworm moth to electric lamps from 1953 through 1964. John G. Taylor participated with Deay in the earlier phase of the work before Taylor's death in 1958. The summary of this series of comparative tests of electric lamps as attractants to the corn earworm moths and of electric light trap designs for its capture included much important information on trapping this insect. The summary follows.

"Of the lamps tested, those (BL, BLB, and sunlamp) which emitted most of their energy in the middle and near ultraviolet regions (320 to 380 nm) of the electromagnetic spectrum attracted more corn earworm moths than did those which emitted either shorter or longer wavelengths. When a combination of lamps of different wavelengths were used in the same trap, the 15-w. BL was the primary attractant in the combination. Increasing the brightness of a 15-w. BL lamp by using 1 20-w., 2 15-w., or 20-w. ballasts increased the number of moths caught, but decreased the life of the lamp. Traps equipped with 5 15-w. BL lamps caught a significantly higher number of moths than did those equipped with either 3 15-w. BL lamps or 5 15-w. green lamps. Blacklight lamps with conventional and with Philips' phosphor were equally attractive. Traps caught more moths when the bottom of a linear 15-w. BL lamp, mounted vertically, was positioned 4-½ inches (¼ its length) below or even with the lip of the trap funnel than when positioned 9 inches below or 9 inches above the funnel lip. Omnidirectional traps caught a significantly higher number of moths than did unidirectional ones. Fan traps caught more, but not significantly more, moths than gravity traps. Unidirectional traps (lamp horizontal) suspended so that the lamp was 12 feet above the ground caught more moths than those suspended so that the lamps were 4, 8, and 16 feet above the ground. Omnidirectional traps (lamp vertical) suspended so that the top of the funnel was 2½ feet above the ground caught more moths than those in which the top of funnel was 5, 7½, and 10 feet above the ground."

Merkl and Pfrimmer (*1955*) compared the catches of various species of Lepidoptera in electric traps with mercury vapor and BL lamps during 1954. The mercury vapor trap is shown in figure 17, page 28, and the BL trap in figure 20, page 31. The two *Heliothis* species, *zea* (bollworm) and *virescens* (budworm) responded similarly to the lamps, but the blacklight appeared to be slightly more attractive.

Pfrimmer (*1955*) conducted studies during 1954 to compare the responses of different orders of insects to three sources of BL radiation as follows: a 15-w. BL lamp, a 15-w. BLB lamp; and three 2-w. argon glow lamps. All the traps used were similar in design to that shown in figure 20. They were grouped in a triangular arrangement within a few feet of each other. The argon lamps were about 3 feet above the ground and the fluorescent lamps about 6 feet. The BLB trap caught twice as many insects as the BL trap and about 12-½ times as many as the argon trap. Although the BLB lamp attracted nearly 2-½ times as many Lepidoptera as the BL lamp, the bollworm response to the BL lamp was greater than to the BLB, and much greater than to the argon lamps.

Pfrimmer (*1957*) during 1955 and 1956 made further comparisons of the attractiveness of different sources of blacklight. He used the 15-w. BL, 15-w. BLB, and 100-w. mercury vapor lamp. The first two were installed in traps similar to those used in 1954 and the last in the trap shown in figure 17, page 28. The bollworm moth responded in greatest numbers to the BL lamp, second to the BLB lamp, and least to the mercury vapor lamp. Slightly more than 50 percent of all moths caught were females.

Callahan (*1957*) reported work on the oviposition response of the corn earworm moth (imago) to various wavelengths of light in laboratory tests initiated in 1955. From these experiments on light and color he concluded that: (1) At equal intensities, no difference was shown in response to 14 percent polarized light and unpolarized light; (2) the higher response was always to the shorter wavelength; (3) the response to green seemed to decline as the night progressed, but the moths seemed to become conditioned and their response to blue built up greatly as the night progressed; and (4) the various oviposition peaks were probably a function of temperature and time of copulation and not directly related to the light experiments.

Hollingsworth, Hartstack, and Lindquist (*1968*) conducted field studies at College Station, Tex., in 1966 to evaluate the influence of total near ultraviolet emission of attractant lamps on insect catches, particularly the bollworm. They found the near ultraviolet output of attractant lamps affected the catches of insects in traps more than any other single factor in these field studies. Increased near ultra-violet emission from the attractant lamp gave increased catch of bollworm moths up to and including a 40-w. BL lamp, the largest used (wattage rating) in these studies. These results verify those reported by Deay and others (*1965*) in which light traps equipped with five 15-w. BL lamps caught significantly more bollworm moths than those equipped with three 15-w. BL lamps or five 15-w. Green lamps.

Corn Earworm Survey Activities With Light Traps

Reference has been made to a survey trap used in a study by Riherd and Wene (*1955*) of moths captured at a light trap at Weslaco, Tex., during the 1-year period, March 1, 1953 to February 28, 1954 (fig. 19, p. 30). It mentioned that the corn earworm moth was collected every month of the year, with a total of 7,400 moths captured. A large number of moths was collected in January. The authors reported that the corn earworm caused severe damage to lettuce during January and February, months which, in the past, had been considered free from the corn earworm.

Deay, Taylor, Barrett (*1964*) reported data on light trap collections of corn earworm adults in Indiana in the years 1953-63. Two types of traps, equipped with BL attractant lamps, were used. The unidirectional type with one 15-w. BL lamp (fig. 16, p. 27) was used throughout, except in one county in 1960-63 and in three additional counties in 1963. The omnidirectional trap (fig. 20, p. 31) was used in these four counties late in the test period and was equipped with either one or three 15-w. BL lamps.

The State of Indiana extends about 285 miles in a north-south direction (lat. 37° 47' to 41° 50' N.). BL insect traps were operated in 14 counties during the years 1953-63 but not in all of these counties in any one year. As a rule, corn earworm moths were collected much earlier in the season in counties in the southern fourth of the State than in the others. In one 8-year study in Lawrence County (lat. 38° 45') and Tippecanoe County (lat. 40° 30') the average difference in the earliest catches was 33 days. In most years, the three peak periods of collection were the first of June and September and the middle of October in the southern part of the State, and two peak periods were the first of September and the middle of October in the northern part.

A special section on light trap collections of certain insects was included in USDA's Economic Insect Report beginning in 1955. The corn earworm (bollworm, tomato fruitworm) was one of the original group of insects on which reports were assembled and has continued to be among that group.

Mangat and Apple in Wisconsin (*1964*), Knowlton in Utah (*1964*), and Hofmaster in Virginia (*1966*) have each reported 8 or more years of corn earworm moth collections in BL traps in their respective States beginning in 1956. In general, they agreed that their light-trapping programs were carried out to expand their knowledge on the flight pattern of this insect and to improve control measures. Mangat and Apple related light-trap catches to temperature accumulations to provide a means of forecasting moth activity in the spring.

Vail, Howland, and Henneberry (*1968*) collected corn earworm moths from traps equipped with 15-w. BL lamps in Home Gardens and Riverside, Calif., in 1964-65, to determine possible correlations between seasonal abundance, mating of females, sex ratios of the collections, and seasonal temperature. The total yearly catch of corn earworm moths by one trap at Riverside was 518 males and 315 females (male:female ratio=1.64): and by four traps at Home Gardens, 1,072 males and 738 females (male:female ratio=1.45). At both locations, the maximum number of moths was caught during the 2-week trapping interval ending September 4, 1964; these maxima were recorded 1 month after the maximum mean temperature was recorded at the two locations. From November 13, 1964, until the end of the experiment in April 1965, few corn earworm moths were caught at either location. The yearly mean number of matings per female was 0.43 and 0.61 at Riverside and Home Gardens, respectively.

Falcon and others (*1967*) made a study of blacklight traps as detection devices for the bollworm in the San Joaquin Valley in 1966. In the study, single light traps were located approximately 1 mile east and west of the test plot and about 3.75 miles apart. Each trap was equipped with an omnidirectional positioned 6-w. BL lamp as the attractant. An assessment of the field populations of bollworm eggs and larvae was made by examining terminals, squares, and both small and large bolls at weekly intervals. There was good correlation between the field counts of bollworm eggs and larvae and the mean number of moths collected in the two light traps.

Corn Earworm (Bollworm) Control Activities With Light Traps

Comments by Michelbacher and Essig (*1938*) on control work by Herms (*1947*) stated that: "During 1936 extensive experimental work with an electrocuting type of monochromatic light trap was conducted. Considerable information of interest was obtained, and some evidence that lights might be used effectively in capturing adults of the corn earworm. However, much more work is necessary in connection with this phase of the investigation."

Taylor and others (*1955*) placed one electrocutor trap on each of the four sides of a square, 1-acre corner plot of a 17-acre field of early sweet corn in southeastern Indiana in 1954. The traps were 36- by 36-inch electrocutor type, each with three 30-w. BL lamps mounted vertically. This plot and a band 100 feet wide bordering it on two sides, totaling 2 acres, was not sprayed. The rest of the field was sprayed four times with a DDT and oil emulsion spray. They found that only 0.4 percent of the corn had earworm damage and 0.6 percent had corn borer damage in the lighted, unsprayed area, while 1.8 percent had corn earworm damage and 1.0 percent had corn borer damage in the unlighted, sprayed area of the field at time of harvest on July 12. Although infestation was apparently light, the four electrical traps controlled insects over the 2-acre area better than the sprays did over the 15-acre area in this test.

Noble, Glick, and Eitel (*1956*) evaluated attempts to control insects with light traps in certain cotton, corn, and vegetable crops in a large-scale experimental installation at Batesville, Tex., in 1955. Growers operated 142 light traps on five adjacent farms comprising a block of approximately 3,000 acres. This acreage, called the trap area, was compared with check fields outside of the area. The traps were 24- by 25-inch electric-grid type, equipped with two 15-w. BL lamps.

Infestation records on the corn earworm were obtained from cornfields by Noble where no insecticides were used. Infested ears averaged 99.5 percent in the light-trap area and 99.3 percent in the check. Light traps also appeared ineffective in controlling the bollworm in cotton. Growers made an average of 8.4 applications of insecticides in the trap area and 8.8 in the check fields. These reduced the larval populations and prevented appreciable crop damage. The electrocutor traps attracted and killed many insects, but very large numbers clogged the grids occasionally and caused loss of trap effectiveness from shortcircuiting. Four gravity-type traps with single 15-w. BL lamps were operated in the area during the experiment to check on insect populations. During a peak, 2-week catch, they averaged 415 bollworm moths per night with a larger number of moths of other economic species in addition.

Stoner and Bottger (unpublished) sampled three cotton-fields weekly from June 2 through September 29, 1964, near Tucson, Ariz., to determine the effectiveness of BL traps in controlling cotton insects. BL traps were spaced at 500-foot intervals around the borders of two fields, 38 and 83 acres, respectively. The fields were less than 500 feet apart. The third field, an 80-acre check field, had no BL traps and was approximately 1 mile from the two trapped fields. On July 23, three-fifths of the 83-acre, BL trap field was treated for thrips with Cygon; July 30, one-fifth of the check field was treated for bollworms with toxaphene and DDT; August 14, three-fifths of the check field was treated with toxaphene and DDT for bollworms. The 38-acre, BL trap field was treated for bollworms August 17, with toxaphene and Dibrom.

They reported that the bollworm population was reduced 40.1 percent in the BL trap fields. Beet armyworm, cabbage looper, cotton leaf perforator, and salt marsh caterpillar were reduced 26.7, 19.4, 38.2, and 43.6 percent, respectively, in the BL trap fields. They commented that "whether the reductions in insects makes the traps a feasible control by themselves is doubtful when proper consideration is given to their cost and operation." A total of 21 fan-type light traps, each equipped with four 32-w. BL circline lamps, were used in this installation on a total area of 121 acres.

H. J. Shipman (1968 unpublished) began monitoring corn earworm populations affecting sweetcorn in the Satus tract, adjoining the Yakima Valley near Mabton, Wash., with blacklight traps in 1954. In May 1966 he installed control traps at a density of approximately three per square mile. The traps used one 15-w. BL lamp mounted vertically between four sheetmetal baffles, placed above a large dishpan of water having 1/4 inch of diesel oil on the water surface. Traps were mounted 8-10 feet above ground level at locations where electricity was already available. Data from inside the Satus light-trap area were compared with similar data from outside.

Where no insecticides were used, fields were compared as to the percentage of worm-damaged ears and the average linear distance between pupae found in the soil. For the period 1966-69, inside the light-trapped area the average distance between pupae was 58 inches and the percentage of damaged ears 25, whereas outside the average distance was 12 inches and 97 percent of the ears were damaged.

Where insecticides were applied, fields were compared on the bases of insecticide applications required and the percentage of clean ears produced. During 1965-68, an average of 3.8 insecticide applications were used to supplement the light traps inside the test area, producing an average of 86 percent clean ears; versus an average of 4.7 applications where light traps were not used, producing an average of 74 percent clean ears.

Shipman concluded, "The light trap control operation has been successful according to all measures ... in three years of operation. Financially it ... (offered) some savings each year. ...light traps eliminated approximately one (pesticide) application per acre...."

Results of a large-scale field evaluation of electric insect traps to reduce bollworm populations in Reeves County, Tex., during 1965 were reported by Sparks (*1967*). About 16,000 acres in a 12- by 35-mile belt devoted primarily to cotton were equipped with about 2,000 electric traps of four basic designs. All the traps were equipped with BL lamps as attractants, but their total lamp wattage varied from 15 to 128 per trap. Three traps were commercially designed, and the fourth was designated as homemade. One commercial trap was the fan type, the other three were gravity type. An evaluation of these trap designs and installations for collecting bollworm moths was made and described by Sparks and others (*1967*). A fan-type trap, with one 15-w. BL lamp, shown in figure 36, page 65, was the standard for comparison of trapping effectiveness of trap designs.

Planned experiments were conducted near the center and on the extreme ends of the light-trapped belt to determine the effectiveness of the traps in controlling lepidopterous insects. In one experiment, comparisons were made among one untrapped and three trapped fields. Oviposition records, taken at irregular intervals in trapped and untrapped fields, failed to indicate that the trapping program consistently produced lower oviposition counts.

In a second experiment, Sparks compared bollworm oviposition and larval count records in a trapped and an untrapped field utilizing chemical control versus no chemical control. No insecticides were used on the trapped field. The egg count record indicates that the insect traps were as efficient as the 10 applications of insecticides in keeping the egg count under control. Again, the light traps appeared to be as effective as the 10 applications of insecticide in controlling populations of bollworm under the conditions of this experiment. In closing Sparks commented: "the system of using traps with BL lamps to reduce insect populations is certainly not a cure for all the insect problems of cotton growers; neither is it something to be overlooked."

Information has been obtained from 1963 through 1966 on corn earworm population suppression by light traps in a large area near Oxford, N.C., that was previously described. Stanley and Taylor (*1965*) reported that, in 1963, light-trap data on corn earworm moth catches showed a 43-percent overall suppression on the population inside the trapped area. This resulted in a 20-percent reduction of corn ears infested with corn earworms. Data from trap catches in 1964 indicated 73 and 82 percent reductions at the enter of the trapped area, as compared with catches made 6 and 14 miles outside the area.

Lam, Stanley, Knott, and Baumhover (*1968*) reported further data on corn earworm reductions in 1965 and 1966. Corn earworm moth captures appeared lower inside the trapped area with 39 and 26 percent reductions, neither of which was significant. However, the eggs and larvae were significantly reduced inside the area by 63 percent in 1965. A 50-percent reduction of earworm eggs and larvae in 1966 was not significant.

Graham and others (*1971*) conducted a study on corn earworm control in corn with a rather dense installation of BL traps in Güemez, Tamaulipas, Mexico, during 1966 and 1967. An installation of 79 suction-type traps, with one 15-w. BL lamp (fig. 36, p. 65), was made in an irrigated field of approximately 20 ha. The traps were placed at intervals of about 200 ft. through the cultivated area. They reported as follows: "data suggest that such an installation of light traps is not useful for protecting an individual field of corn from damage by the corn earworm. However, it is possible that an installation of traps over a large area could have an impact on the total corn earworm population if the density of traps was sufficiently high."

Corn earworm moth catches have been recorded for the 3-year period, 1967-69, in an extensive experimental light trap installation at Red Rock, Ariz. The 415 light traps and the 2,240-acre cropped area covered are described in

Table 1.—Summary of light trap collections, 1967-69

Distance from border (ft.)	Corn earworm moths caught per trap per night					
	Female			Male		
	1967	1968	1969	1967	1968	1969
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
0 (border)	6.35	1.18	0.99	5.35	1.02	1.06
1,000	8.40	1.12	1.49	9.59	1.04	1.84
2,000	9.34	1.12	1.32	9.09	1.03	1.53
3,000	5.93	1.01	1.07	4.81	0.82	1.09
4,000 or center	4.64	0.81	1.12	4.45	0.62	0.87

detail under cabbage looper control. A summary of the catches of both sexes of corn earworm moths is presented in table 1. The reductions in corn earworm moth catch from 1967 to 1968 and 1969 are clearly evident.

Pink Bollworm Survey and Control

Maxwell-Lefroy (*1906*) is the first entomologist, found by the author, to record capturing pink bollworm moths in lamp traps. However, the use of light traps was indicated as a method of treatment still in the experimental stage. Others including McLelland and Sahr (*1911*), Willcocks, (*1916*), Gough (*1918*), and Ballou (*1920*) all concluded that the moth probably was attracted to lights.

Busck (*1917*) on the contrary, concluded that "from very many and repeated observations under different conditions it may be definitely stated, not withstanding the many other statements to the contrary that *Pectinophora gossypiella* is not attracted to light, but is, on the contrary, shy of all light, natural and artifical." Loftin and others (*1921*) in their studies in Mexico also indicated there was no attraction whatsoever to lights by pink bollworm moths.

Several years later Chapman and Noble (unpublished) conducted limited experiments at Presidio, Tex., in 1929 and found that the pink bollworm moths were attracted by light, but they could make no definite statement as to the proportion coming to the differently colored lights. Little difference in attracting moths was found between a 100-w. clear lamp and a 75-w. blue-daylight lamp.

Husain and others (*1934*) reported the attraction and capture of pink bollworm moths by light traps in the Punjab during 1929-31, using an incandescent gas lamp of 200 cp. as the source of light. Moths were trapped in the field from about the middle of July to the first week of November. The largest number collected during 3 years, however, was from the middle of September to the middle of October.

Pink Bollworm Moth Attraction to Light and Effects of Trap Design on Moth Capture

Glick and Hollingsworth (*1954*) discovered the attraction of ultraviolet radiation to the pink bollworm moth in Texas during 1952. A field test was made to determine whether the newer ultraviolet lamps and traps developed for survey and possible control of the European corn borer and hornworms, might possibly be applied to the pink bollworm. The two traps and lamps used—a horizontal, funnel-shaped trap with 100-w. mercury vapor lamp and a fan-type trap with four 15-w. vertically mounted BL lamps—were both successful in attracting and capturing pink bollworm moths. During a single night, approximately 50,000 pink bollworm moths were collected in the funnel-shaped (mercury vapor) trap and about 112,000 in a suction trap with suction-fan motor made inoperative. Both traps are shown in figure 18, page 29. While the suction-type trap appeared to be more effective than the funnel-shaped trap in attracting the pink bollworm moth, the latter type was used immediately for survey because of its lower initial and operating cost.

Glick and Hollingsworth (*1955*) conducted laboratory tests in 1953 with 28 lamps or combination of lamps having radiation outputs that covered various regions of the electro-magnetic spectrum between 184.9 nm (ozone lamp) and 1,200 nm (infrared drying lamp). Of the several sources tested, only one single lamp proved to be more effective than the 15-w. BL fluorescent lamp—a 100-w. spot-type, mercury vapor lamp (H100-SP4) equipped with a filter which transmitted primarily in the near ultraviolet region. The principal radiation from this lamp is in the near ultraviolet region of the spectrum. Lamps that had their principal radiation in the visible portion of the spectrum attracted few moths.

Further studies on the attraction of pink bollworm moths made by Glick, Hollingsworth, and Eitel (*1956*) in 1954, verified the greater response to lamps that radiated in the near ultraviolet (blacklight) region. Low-wattage near ultraviolet or 2-w. argon glow lamps were found to be nearly as attractive to pink bollworm moths as the higher wattage near ultraviolet lamps, but much less attractive to insects in general. These findings provided the basis for the design of special argon lamp, electric insect traps (fig. 22, p. 37) for pink bollworm survey work.

Tsao (*1958*) reported results on the trapping of pink bollworm and other cotton insects by using the BL fluorescent lamp, during 1956 and 1957 in China. He compared a 15-w. Philips ultraviolet fluorescent lamp with a 40-w. BL fluorescent lamp in traps of similar construction. These were imitations of Glick and Hollingsworth's 1954 model for an ultraviolet fluorescent lamp. Of necessity, the BL trap was made longer since the BL lamp measured 120 centimeters long, while the Philips ultraviolet was only 44 cm. In the BL trap, one end of the lamp protruded into the collecting funnel by about 24 cm.

Tsao's study was conducted initially in a 1/16-acre, screened cage where he compared the two lamps listed with a third lamp, an ordinary 15-w. blue bulb. Radiation from the blue bulb peaked at 470 nm, the ultraviolet lamp at 400 nm, and the BL lamp at 365 nm. This test indicated that the pink bollworm moths respond most to the lamp having wavelength in the near ultraviolet region. A field test was made with the two traps equipped with the Philips ultraviolet lamp and the BL lamp. This again proved the BL lamp was more attractive to the pink bollworm moths than the Philips ultraviolet lamp. As a result, BL lamp traps were adopted for detection of pink bollworm emergence and migrating studies in the Chinese cotton belt.

Zlokovic, Stancic, and Tadic (*1958*) studied the attraction of ordinary white light and ultraviolet (blacklight of 3,600 A) to pink bollworm moths in Yugoslavia during 1957. Their best results were achieved with a quadrangular trap with working electrodes on all lateral sides. They reported a catch of nine moths in 2 months by the trap with ultraviolet lamp and none with the trap with white light, indicating that the trap with the ultraviolet lamp could be recommended for use in other regions.

Laboratory investigations of the spectral response characteristics of pink bollworm moths were conducted by Hollingsworth (*1961*) in 1957, 1958, and 1959. In one series of tests the response of pink bollworm moths to 18 narrow wavebands between 280 nm and 625 nm was determined by comparison with a 365 nm source. In another series of tests, 10 wavelengths between 315 nm and 580 nm were selected for comparative responses and each wavelength was compared with every other wavelength. The spectral responses in the two series of tests were very similar. Under the low radiant energy level employed, the peak response was indicated at approximately 515 nm (green). Decreased response occurred in the vicinity of 415 nm and then a secondary peak response occurred in the near ultraviolet region at about 365 nm. There was very little response to wavelengths longer than 600 nm or shorter than 300 nm.

Hollingsworth (*1961*) made a third series of tests relative to the spectral response characteristics of pink bollworm moths in a larger test chamber to determine the effect of intensity or energy level. The experiment was designed for comparison of 365, 405, and 515 nm at wavelength energy intensity levels of 20, 40, and 80 times that used in the previous two tests. At the twentyfold energy level there was no shift in response characteristics, that is, 515 nm remained more attractive than 405 and 365 nm, and 365 nm was more attractive than 405. At the fortyfold level, a shift occurred in the response characteristics and 365 nm became more attractive than 515 and 405 nm, with 405 remaining the least attractive. Approximately the same relationship continued to exist at the eightyfold level with a slight increase noted for 405 nm when compared with 365 nm. The author did not attempt to explain the shift in peak response from the green at low energy levels to the near ultraviolet at increased energy levels.

The catch of male pink bollworm moths in light traps equipped with BL lamps has been increased when baited with sex attractants prepared from 3- and 8-day-old virgin females or of synthetic preparation (hexalure). Guerra and Ouye (*1967*) reported that when different types of traps were used in field cages to capture male pink bollworms, traps equipped with a lighted BL lamp and baited with sex attractant were the most effective. Bariola and others (*1971*) found in 1969 studies that standard insect survey light traps, equipped with a 15-w. BL lamp and baited with hexalure caught more male pink bollworm moths than light traps without hexalure or hexalure traps alone. Further study of this combined use of radiant energy and pheromone is needed to determine reasons for variance in catches during seasonal and shorter periods of time.

Pink Bollworm Survey Activities With Light Traps

The first major collection of pink bollworm moths by a light trap with ultraviolet lamps was made in July 1952 in Texas as reported by Glick and Hollingsworth (*1954*). This discovery created an urgent need for a survey trap to aid in determining areas newly infested by this pest. To meet this need, the funnel-shaped trap with mercury vapor lamp was selected. One such trap was placed near cottonfields at four locations in the Corpus Christi area in August. In September, six such traps were placed in northeastern Texas—with two each in three counties not known to be infested with the pink bollworm at that time. During October one moth was taken in each county. Additional traps were placed in operation during 1952 at eight different locations in Texas, five in Louisiana, and one in Mississippi.

A trap designed and constructed by Hollingsworth, in late 1952 was smaller than the suction-type trap used in the pink bollworm detection tests in Texas in 1952 (see fig. 19). Modifications were made in this design after limited use as a survey trap, during 1953 primarily in the cotton areas, to include a larger, metal insect collection chamber, to incorporate a drain device in the funnel, and to omit the roof. This omnidirectional BL trap was then tested in comparison with the funnel-shaped trap and mercury vapor lamp and the unidirectional trap developed in Indiana as shown in figure 18, page 29. Results of this test by Hollingsworth and Carter (unpublished) showed that the omnidirectional trap with one 15-w. BL lamp or three 2-w. argon glow lamps caught more pink bollworm moths than the other two traps. A group of three 2-w. argon glow lamps was nearly as effective as a 15-w. BL lamp in attracting pink bollworm moths, but was much less attractive to insects in general. This trap with both types of lamps is shown in figure 20, page 31. This selective feature made the argon glow lamp very desirable as the attractant in survey traps for the pink bollworm, particularly during periods of heavy insect flight. Much less work was required in examination of collections for the presence of pink bollworm moths because fewer insects were attracted by the argon glow lamp than by the 15-w. BL lamp.

The favorable response to light traps for pink bollworm survey work was shown by the following statement in the Seventh Annual Report on Cotton Insect Research and Control:[12] "Pink bollworm inspections to determine the degree of infestation in individual fields should be made as follows; 4: Light traps; especially designed traps, using mercury vapor or BL fluorescent lamps, will attract pink bollworm moths. Such traps have been used to discover new infestations and their usefulness and value for survey work should be fully explored." The annual conference reports continue to mention this need.

During 1954, light traps were operated in 16 different seed storage houses for detecting pink bollworm infestations in stored cotton seed. Pink bollworm moths were collected at 9 of the 10 locations having pink bollworm infestations as determined by gin trash examination. While the traps mentioned here were used chiefly in Texas, seven were located in five other adjacent States.

Location of a new pink bollworm outbreak west of Phoenix, Ariz., in July 1958 created a need for additional survey traps to detect new infestations of this pest in Arizona or possibly in California. As a result, about 150 traps with BL lamps were installed in Arizona and California in 1958 by the agriculture departments of those States in cooperation with the Plant Protection Programs, U.S.D.A.[13] This number of traps was increased to a total of 254 in 1958, with 124 in California and 130 in Arizona. The argon lamp was the preferred attractant but many traps were equipped so that either a BL lamp or argon lamp could be used. The operation of these traps in California was reported by Berry and others (*1959*).

Electric traps with and without a bait consisting of a neutral or synthetic chemical sex attractant have been compared directly and with a trap equipped with sex attractant alone. As indicated previously, Guerra and Ouye (*1967*) found that when different types of traps were used in field cages to capture male pink bollworms, traps equipped with a lighted BL lamp and baited with sex attractant, prepared from 3- to 8-day-old virgin females, were the most effective. However, the efficiency of this trap was not a result of the trap design per se, but of the combined attraction of the pheromone and the light. The light increased the total number of pink bollworm males trapped and also captured adult female pink bollworms. Some disadvantages of this trap given by the authors are the cost of the trap and the cost of its operation.

Keller and others (*1969*) reported that the synthetic chemical sex attractant, hexalure, was more effective as an attractant for male pink bollworm moths than the natural lure, a crude extract of virgin females. Further comparisons were made at three locations in 1969 to determine whether traps with BL lamps and hexalure were more effective than the BL

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[12] Beltwide Cotton Production-Mechanization Conference held at Memphis, Tenn., Dec. 14-15, 1953.

[13] See footnote 7, p. 32.

traps or hexalure traps alone in attracting male pink bollworm moths. Bariola and others (*1971*) reported that BL traps with hexalure caught more male pink bollworm moths than light traps without hexalure or hexalure traps alone. Traps with hexalure alone appeared to be less efficient in catching males in high populations than in low populations.

Pink Bollworm Control Activities With Light Traps

During 1953, the year following the discovery of pink bollworm moth attraction to near ultraviolet radiation, two types of light traps were tested in cottonfields by Pfrimmer and others (*1955*) in Cameron County, Tex., in order to evaluate them as a possible means of controlling the pink bollworm. Despite the presence of the light traps adjacent to the cottonfields, the infestation of pink bollworms increased in each of these fields throughout the period when the cotton was fruiting. Where suction traps were used, the seasonal average infestation was higher in the vicinity of the trap than in the rest of the field, a possible indication that these traps were drawing the moths in from the distant parts of the fields. In the fields in which backboard traps (fig. 34, p. 62) were used, the distance from the trap made little difference in the infestation. The authors concluded from these tests that the use of these traps for controlling the pink bollworm did not seem warranted.

During 1954, Glick and others (*1956*) operated an electrocutor-grid trap equipped with two 15-w. BL fluorescent lamps on a 1/20-acre plot of cotton enclosed in a tightly screened cage to determine whether it could prevent a pink bollworm infestation. A similar plot without a trap was used as a check. Although the trap caught 2,163 moths from June 3 to July 14, there was no appreciable difference in rate of buildup in infestation between the light-trap and check sections. The authors observed that this lack of reduction in infestation of the trap section, despite the high moth catch, indicates that moths deposit eggs before being trapped.

Noble and others (*1956*) evaluated a large-scale, experimental light-trap installation for control of the bollworm and other cotton, corn, and vegetable insects at Batesville, Tex., in 1955. They obtained records on pink bollworm infestation as was done on the bollworm. Records showed that the insecticides used for bollworm control were also effective against the pink bollworm except in one field treated with endrin. Although the percentage of bolls infested was slightly lower in the trap area, this difference could not be attributed to control by light traps. As in the case of the bollworm, the infestation counts in representative fields of the trap area and in the check fields outside the area showed that the electric grid traps were of no benefit in the control of the pink bollworm. Hollingsworth, observations on the operation of these traps (unpublished), indicated that the design of the traps needed considerable modification to effectively destroy all of the insects attracted to the area. Thus, future possibilities of successful population reduction of pink bollworm moths most likely depend upon improvements in trap design combined with use of more effective attractants.

Tobacco Budworm Survey and Control

Howard (*1900*) mentioned that there are two distinct and rather similar tobacco insects known as budworms, which occur frequently together in the same field and work in a somewhat similar manner. He distinguished between them by calling one *H. virescens*, the true budworm and the other *H. zea*, the false budworm. The latter, frequently called the cotton bollworm, has been recognized as a major cotton pest for the past century (Riley, *1885*). According to Newsom (*1964*) the former has been recognized as a major cotton pest since about 1934.

Walkden and Whelan (*1942*) are the first found by the author to have reported the capture of the tobacco budworm (*H. virescens*) in electric insect traps. Their information was obtained during 1935-37, through the operation of light traps located at six widely separated points in Kansas and Nebraska. The lamps and traps used have been described, and the trap is shown in figure 15, page 26. The catches were small and not made by every trap each year operated. However, these catches did indicate that the tobacco budworm was attracted to light and further that the insect existed in an area where its major hosts, tobacco and cotton, are not usually grown.

Tobacco Budworm Moth Attraction to Light and Effects of Trap Design on Moth Capture

A study by Girardeau and others (*1952*) in Georgia reported on the attraction of three types of electric light traps to hornworm moths and to bollworm moths. Records were also collected on the capture of the tobacco budworm in the same traps. This insect was taken in much smaller numbers (about 11 percent of trap collections) than was the cotton bollworm. The suction-type trap was the most effective of the traps used. It attracted and captured 70 percent of the total number recorded while all six traps were operated from April 8 to August 25, 1951. The total catch of tobacco budworm moths by the suction trap for the entire period of trap operation, April 8 to October 20, was 1,064, the first substantial catch of tobacco budworm moths by an electric insect trap known to the author.

During the study conducted by Glick and Hollingsworth (*1954*) in Texas on the attraction of the pink bollworm moth to insect traps equipped with mercury vapor or BL lamps in 1952, the capture of tobacco budworm moths in the same traps was recorded by Glick (unpublished). Moth captures were made in significant numbers in Southeastern Texas during June, July, and August. Glick also noted a report on October 13 from E. W. Dunnam, Stoneville, Miss., as follows: "Mr. Furr has noted that when the temperature drops to 40° F. the tobacco budworm disappears from the collection, but cotton bollworms are still caught in large numbers."

Merkl and Pfrimmer (*1955*) investigated the catches of various species of Lepidoptera during 1954 in traps with mercury vapor lamps at Stoneville, Miss., and Tallulah, La., and in a BL trap at Tallulah. The funnel-shaped trap with mercury vapor lamp was that used by Glick and Hollingsworth (*1954*) and is shown in figure 17, page 28. The BL trap was that developed in Texas and is shown in figure 20, page 31. They found that the budworm responded similarly to the lamps, being attracted slightly more to the BL lamps than to the mercury vapor lamp.

During 1955 and 1956, Pfrimmer (*1957*) continued to study the response of insects to different sources of blacklight. He used traps similar to those employed at Tallulah, La., in 1954, with the addition of a third BL trap equipped with a 15-w. blacklight-blue (BLB) lamp. The greatest tobacco budworm catch in 1955 was made in the trap with the BL lamp—about twice that with the BLB and 2.5 times that with the mercury vapor lamp. In 1956 with generally smaller catches, traps with BL and BLB lamps caught about equal numbers, but these traps caught three times as many budworm moths as the trap with a mercury vapor lamp.

Newcomb (*1967*) conducted laboratory and field cage experiments to compare the responses of the bollworm and budworm moths to radiant energy. He found no important differences in catches of either species that could be attributed to sex. A significant reduction in budworm moth response was due to the moths' increasing age, not to mating. He also found that the radiant energy level, to which the insects were exposed, had more effect than the wavelength on the rate of light adaptation. Results of all the tests indicated that more moths of both species could be caught by either increasing the energy output of the trap lamps or by using a greater number of traps to reduce the distance over which the moths have to be attracted.

Hendricks (*1968*) conducted an experiment in 1967 to study the complementary effects of using BL lamps for trapping male tobacco budworms. For 19 weeks he compared the numbers of male tobacco budworm and bollworm moths caught in three BL insect traps baited with virgin female tobacco budworms and those caught in three similar, unbaited traps in a 4.3-acre cottonfield. He found there was a significant increase in BL insect trap catch of male tobacco budworms when the traps were baited with female virgins of the same species. However, the difference was not obvious until compensation was made for at least two influential variables—light trap location and wind.

Tobacco Budworm Survey Activities With Light Traps

A study of moths captured at a BL trap at Weslaco, Tex., March 1, 1953, to February 28, 1954, by Riherd and Wene (*1955*), was mentioned earlier. They recorded by months the number of tobacco budworm moths captured. Their records showed that a total of nine moths was taken during May, June, August, September, and February of the 1-year test.

The tobacco budworm was one of the original group of nine insects listed in the special section on insects caught by light traps, published weekly in USDA's Economic Insect Report since 1955.

Parencia, Cowan, and Davis (*1962*) reported on the relationship of Lepidoptera light-trap collections to cottonfield infestations. The report was based on five species of cotton insects collected in a 7-year period, 1955-61, near Waco, Tex. During 1953 and 1954, the pink bollworm alone was collected. A trap with mercury vapor lamp was used from 1953 through 1957, and subsequently, a trap with one 15-w. BL lamp was employed. A total of 771 tobacco budworm moths was collected in the 6-year period, 1956-61. Most of the moths were captured during the July-September period, although some were taken as early as May and as late as November.

Glick and Graham (*1965*) also made and reported seasonal light-trap collections of Lepidopterous cotton insects in south Texas over a 5-year period (1959-63) in the lower Rio Grande Valley. The traps used were equipped with either a single 15-w. BL lamp or three 2-w. argon lamps. In 3 of the 4 years that tobacco budworm specimens were collected, peak numbers occurred in August. Seasonal occurrence of these moths in light-trap collections varied from May through October. Collections of this species often varied considerably between trap locations.

Gentry and others (*1971*) collected information from 13 light traps, in a 1,200-trap installation in north Florida, during 1966 through 1968. The information concerned seasonal abundance and mating frequency of the tobacco budworm. The attractant was one 15-w. BL lamp mounted in a trap of the type shown in figure 33, page 61. They found that seasonal peaks of population occurred several times each year but always after the tobacco crop had been harvested and the stalks destroyed. The catches of male moths were generally higher than the catches of female moths.

Tobacco Budworm Control Activities With Light Traps

The large-scale light trapping experiment that was installed by Lawson and others (*1963*) near Oxford, N.C., in 1962, was discussed in the section "Hornworm control activities with light traps." While the main effort was to suppress hornworm moths, efforts were also made to reduce corn earworm and tobacco budworm populations.

Stanley and Taylor (*1965*) reported observations made in the Oxford light-trapped area during 1963 and 1964, on the effect of light traps on populations of the tobacco budworm. In 1963, estimates of feeding damage by tobacco budworm indicated a 93-percent reduction at the center of the 113-square-mile area, as compared with damage 6 miles outside of the area. Similar counts in 1964 showed reductions of 56 and 72 percent at the center of the trapped area, as compared with conditions 6 and 14 miles outside the area.

Lam and others (*1968*) further reported on reductions in tobacco budworm populations in the Oxford area during 1965 and 1966. Although fewer tobacco budworm moths were captured by light traps outside than inside the area during both years, the differences were not significant. However, budworm eggs and larvae were significantly reduced 63 percent inside the area in 1965. A 50-percent reduction of budworm eggs and larvae in 1966 was not statistically significant. Calculated reductions in damage to tobacco by the budworm and earworm were 39 percent for each of these 2 successive years, but the data were not statistically significant. Many factors other than light traps may have influenced the differences in tobacco insect populations measured inside and outside the area. Two important factors could be tobacco stalk cutting and insecticide applications.

Studies conducted in 1965-66 by Gentry and others (*1969*) gave encouraging results on the possibilities of integrated control as an improved means of reducing populations of shade-grown tobacco pests. Integrated insect control is a method of reducing or suppressing populations of insects by using combined effects of several methods of control. In this case, blacklight traps, systemic insecticides, and supervised insecticide treatments were combined. Although the practical value of integrated control could not be fully established on the basis of this study, the integrated program was just as effective as the conventional program.

Results of further studies to determine the effectiveness of the above integrated insect control program conducted during 1967, 1968, and 1969 were reported in 1970 by Gentry and others (unpublished). As in 1965 and 1966, omnidirectional light traps with two vertical 15-w. BL lamps were operated on all four sides of the tobacco fields about 50 feet from the shade wall and spaced about 160 feet apart (fig. 37, p. 86). Damage by the tobacco budworm in 1967, 1968, and 1969 was reduced 64, 73, and 80 percent, respectively, compared with a conventional insecticide program. About 50 percent fewer applications of insecticide for control of the tobacco budworm and cabbage looper were made on the integrated control program, thus insecticide residues were reduced accordingly. The reduction in insect damage and the fewer insecticide applications also greatly reduced the cost of control to the participating growers.

Cabbage Looper Survey and Control

Collections of Lepidoptera at light traps were made during 28 full nights between May 14 and September 13, 1918, by Turner (*1920*) at Hagerstown, Md. The light trap equipment used was described previously in a report of his early work. He recorded the capture of 147 cabbage looper moths, 58 of which were females, during that period. This is the first published report found by the author of light-trap collection of this insect.

Figure 37.—Omnidirectional gravity-type light traps with two 15-w. BL lamps operating adjacent to shade-grown tobacco field.

Dirks (*1937*) reported the capture of 29 cabbage looper moths in light traps in Maine, during 1932-34. Five of the total catch were females. His light trap equipment is mentioned earlier under insect attraction to radiant energy.

A few years later, 1934-37, Walkden and Whelan (*1942*) found considerable response of the cabbage looper to light traps that were placed at six locations in Kansas and Nebraska. A season's catch, from March 13 to November 1, 1935, by one trap totaled 3,512 moths. In the group of 528 moths examined for sex, 58 were females. The equipment was that used in their study of owlet moths taken at light traps (fig. 15, p. 26).

Cabbage Looper Moth Attraction to Light and Effects of Trap Design on Moth Capture

Catches of cabbage looper moths at Tifton, Ga., in 1951, were recorded by Girardeau and others (*1952*). The largest number of this moth, taken by the suction trap, was 165 for the period April 8 to August 25. The grid trap captured 134 moths, and the gravity-type traps from 12 to 29 moths during the same period. Designs of these traps and lamp types with which they were equipped are described in the section on hornworm attraction to light. An identical suction trap operated singly in an attraction test at College Station, Tex., during 1951, captured 693 cabbage looper moths from mid-August through October 9, according to Rainwater (unpublished). The maximum catch was 270 moths in a single night during September.

Glick and Hollingsworth (*1955*) conducted laboratory and field investigations during 1953 at College Station, Tex., to determine which lamp had the greatest attraction for the cabbage looper moths. In laboratory tests, the following lamps were compared directly with a 15-w. BL lamp as the check: 15-w. germicidal, 20-w. fluorescent sunlamp, 275-w. RS sunlamp, 15-w. BLB fluorescent, and a 2-w. argon glow lamp. Of this group, only the RS sunlamp created a greater response from this moth than the 15-w. BL check.

The field tests mentioned in the preceding paragraph were conducted to determine the optimum number and type of near-ultraviolet lamps for use in insect-collecting traps. Comparison was made of 15-w. BL and BLB fluorescent lamps in traps of the type used for similar tests with the cotton bollworm. In one test, traps were compared with 1-, 2-, or 3-, 15-w. BL lamps. In a second test, 1-, 2-, or 3-, 15-w. BLB lamps were compared with one 15-w. BL. In the third test, 1-, 3-, or 4-, 15-w. BL lamps were compared with one 15-w. BL lamp. The results indicated that the single 15-w. BL fluorescent lamp is the most efficient light source per watt of input, for collecting cabbage looper moths in traps of the type tested.

Merkl and Pfrimmer (*1955*) reported the catch of cabbage loopers by a light trap with 100-w. mercury vapor lamp at Stoneville, Miss., January 1 to September 30, 1954. This trap is of the same design as that used by Hollingsworth in 1952 for capturing the pink bollworm (fig. 17, p. 28). They reported a total catch of 5,136 moths for the season with a maximum number caught per night of 550. During 1955 and 1956, Pfrimmer (*1957*) studied the response of insects (including the cabbage looper) to different sources of blacklight. He used a 15-w. BL and a 15-w. BLB lamp in traps similar in design to that developed by Hollingsworth for insect surveys (fig. 20, p. 31). The third trap with a 100-w. mercury vapor lamp was the same as the one he used in 1954. During both years, the BL lamp attracted the greatest number of moths, with the mercury vapor lamp second highest in 1955 and lowest in 1956.

Vail and others (*1968*) collected cabbage looper moths from omnidirectional gravity-type traps equipped with 15-w. fluorescent BL lamps in Home

Gardens and Riverside, Calif., during 1964-65. A total of 2,674 male and 2,355 female cabbage looper moths were captured by four traps through the year (April 1964 to March 1965) at Home Gardens; at Riverside, 727 males and 233 females were captured by one operating trap. Based on moths caught per operating trap the results were similar except for the yearly male: Female ratios – 1:14 and 3:12 at Home Gardens and Riverside, respectively. The peak moth catches for both areas (28.9 per trap night at Riverside) occurred very close to the time when maximum temperatures were recorded. The mean number of matings per female were 1.26 at Riverside and 1.25 at Home Gardens.

Shorey and Gaston (*1965*) compared the response of male cabbage looper moths in a flight tunnel to a current of air containing female sex pheromone and to a 75-w. tungsten-filament lamp. They found that when low-intensity light and pheromone odor were present in the tunnel at the same time, male orientation toward the pheromone source was completely abolished, and most of the males congregated adjacent to the light source.

Henneberry and Howland (*1966*) studied the response of male cabbage loopers to blacklight with or without the presence of the female sex pheromone, in the field at Home Gardens, Calif., and in the laboratory at Riverside, Calif., in 1964. They reported that 29 to 30 times as many male cabbage looper moths were caught in light traps with 15-w. BL lamps baited with 50 virgin female cabbage looper moths than in similar unbaited traps. Further, 10 to 15 times as many males were caught in light traps operated 200 feet from baited traps than were caught in similar unbaited traps situated at least 1 mile apart and 1 mile from the baited traps. In the laboratory studies, more male cabbage looper moths responded to blacklight when female sex pheromone extracts were introduced than those responding to the sex pheromone or to blacklight alone.

Results of additional related studies conducted at Riverside, Calif., in 1965 were reported by Henneberry, Howland, and Wolf (*1967a*). As in 1964, when traps fitted with a BL lamp were baited with caged virgin female cabbage looper moths, increased numbers of male cabbage looper moths were caught compared with numbers in similar unbaited traps. The numbers of male moths caught in the baited traps increased as the number of virgin females was increased. Virgin females placed as much as 40 feet from the trap, increased the numbers of male moths caught. The catch was not increased when male cabbage loopers were used as bait or when the dispersal of the female sex pheromone was prevented. Male cabbage loopers had a definite peak of nocturnal activity, measured by trap catches during the known period of maximum mating activity.

Hollingsworth and Hartstack (unpublished) conducted laboratory studies on the spectral response of cabbage looper moths in a V-shaped test chamber during 1966. The results showed a peak response by the cabbage looper in the near ultraviolet region with a secondary peak in the 475-525 nm region.

The field studies conducted in 1966 by Hollingsworth and others (*1968*) to evaluate the influence of total near ultraviolet (320-400 nm) emission of attractant lamps on insect catches in traps, previously described in the section "Bollworm attraction to light," also included the cabbage looper. Catches of cabbage looper moths, like those of bollworm moths, were affected more by the near ultraviolet output of attractant lamps than by any other single factor. Increased near ultraviolet emission from the attractant lamp (up to and including a 40-w. BL lamp, the largest wattage used in these studies) gave increased catch of cabbage looper moths.

Wolf, Kishaba and others (*1967*) experimented with various materials, such as Monterey sand, paraffin, and silica gel, as carriers for a synthetic cabbage looper sex pheromone in laboratory and field tests. The synthetic looper sex pheromone had been identified, isolated, and synthesized by Berger (*1966*). Monterey sand was found to remain attractive much longer in the laboratory than other materials treated with the synthetic pheromone. This sand was utilized in field tests on the attractancy of the sex pheromone at various concentrations. In these tests the sand showed promise as a carrier for the synthetic pheromone.

The attractancy of the sex pheromone at various concentrations in sand was evaluated by comparing the effectiveness of traps equipped with 15-w. BL lamps baited with the synthetic pheromone or with virgin females against unbaited light traps, or against carton traps baited with either the synthetic sex pheromone or with virgin females. Their results showed that standard survey light traps, previously described, equipped with BL lamps and baited with 100,000 micrograms (μg.) of the synthetic pheromone caught as many male moths as those baited with 100 virgin females during the first 2 weeks and more during the 3rd, 4th, and 5th weeks. However, they attracted fewer during the 6th and 7th weeks. Light traps baited with either 100 virgin females or with 100,000 μg. of the pheromone caught several times more male moths during the 7-week period than the light trap alone.

In further related work, Kishaba and others (*1970*) compared a special electric grid trap with the standard survey light trap with and without the synthetic pheromone. This grid trap, collection container, and enclosing fence are shown in figure 38. It consisted essentially of five fly electrocuting grids assembled in box form with the bottom open. When used, a 15-w. BL lamp was suspended in the center of the grid units. Grid traps of this design, baited with cabbage looper synthetic pheromone caught more male cabbage loopers than standard survey light traps with the pheromone. When these pheromone-baited grid traps were operated with a 15-w. BL lamp, they caught 1.3 times more males than similar baited traps without the lamp.

Figure 38.–Electric grid trap, consisting of five fly electrocutor devices, with the fly bait traps removed, assembled in a box form with bottom open.

Cabbage Looper Survey Activities With Light Traps

In the 1-year study made by Riherd and Wene (*1955*) at Weslaco, Tex., on collection of insects by a gravity-type trap equipped with four 15-w. BL lamps mounted vertically, large numbers of cabbage looper moths were collected during every month. The total catch for the year was 10,271 moths with largest catch in September and next largest in March.

Parencia and others (*1962*) collected cabbage looper moths at Waco, Tex., in a light trap for the 6-year period 1956-61. The light trap used in 1956 and 1957 was of the horizontal, gravity-unidirectional type with 100-w. mercury vapor lamp developed by Taylor for use in studies of European corn borer. The trap used during the other 4 years was the omnidirectional, gravity-type trap with 15-w. BL lamp mounted vertically, developed by Hollingsworth. Annual cabbage looper moth catches were 49,863 in 1956 and 9,902 in 1957 by the mercury vapor lamp trap. Similar catches by the trap with BL lamp varied from 15,018 to 25,336 during 1958-61. Moths were usually collected beginning in April and ending in November, with maximum catches in August.

Glick and Graham (*1965*) also collected cabbage looper moths in light traps. Their collections over the 5-year period, 1959-63, were made at five locations in the lower Rio Grande valley of Texas. Traps used were of the omnidirectional type, equipped with either a single 15-w. BL lamp or three 2-w. argon glow lamps mounted vertically (fig. 20, p. 31). They found that cabbage looper moths were taken in greatest numbers in July in 4 of 5 years, with minor peaks of abundance in the spring and fall. Further, they found that collections did not vary greatly among locations, indicating a more or less uniform population.

In 1963, the cabbage looper was added to the list of insects collected in light traps in the Economic Insect Report. This addition served to further recognize cabbage looper attraction to blacklight radiation.

The study of BL traps as detection devices for the bollworm by Falcon and others (*1967*) in 1966, also included the cabbage looper. The same installation of insect traps with 6-w. BL lamps, used for the bollworm, served for the cabbage looper study. They reported that BL insect traps effectively trapped cabbage looper moths in a cottonfield. Also, they reported that increased collections of moths in the traps were followed by a rise in egg and larval populations in the field. In addition, they indicated that light-trap information used with established field-checking procedures can aid in determining the need for control measures of this pest.

Cabbage Looper Control With Light Traps

Noble and others (*1956*) evaluated the attempts by growers to control cotton and pink bollworms with 142 light traps on approximately 3,000 acres, about one trap per 21 acres (see p. 81). They made three observations of the cabbage looper in crops consisting of broccoli, brussel sprouts, cabbage, cauliflower, and lettuce in October, November, and December after the cotton-growing season. They concluded that the light traps were of no benefit for control of the cabbage looper. Mention was also made of observations by Hollingsworth on the operation of these traps (unpublished) and that the design of the traps needed considerable modification to effectively destroy all of the insects attracted to the area.

Cabbage looper infestation in early cabbage, grown in 60-foot-square garden plots, was lighter in plots protected by multiple lamp insect traps than in check plots as reported by Deay, Taylor, and Johnson (*1959*). Similar results were found by Hartsock and Deay (unpublished) on late cabbage in 1960.

Equipment for an extensive experiment on the combined use of sex pheromone and electric traps for cabbage looper control was installed and its operation initiated near Red Rock, Ariz., in March 1967, as reported by Wolf and others (*1969*). The site for this experiment was a 3,110-acre ranch of which 2,240 irrigated acres were cropped. Lettuce was grown on 1,800 acres–1,000 for a fall crop and 800 for a spring crop. Cotton was usually grown on 200 acres each year.

The light trap installation in this experiment included 415 barrel-mounted traps for insect control purposes and 43 traps for monitoring adult moth populations. The two types of traps were identical with the exception of the insect collecting container. Lamps and baffles of control traps were mounted on 55-gallon barrels and fastened to them by a locking ring. The survey traps were equipped with an 18-inch diameter funnel and killing container. Both traps had two 15-w. BL fluorescent lamps, with baffles extending radially in four directions. The two traps are shown in figure 39. Cabbage looper pheromone dispensers are located at the top of the traps. Initially sand dispensers were used; but after 6 months' operation, they were replaced with wick dispensers.

The catches of adult cabbage loopers were assembled into five groups based on the distance from the outside border of the trapped area. A summary of the numbers of moths caught per trap per night during the 3-year period, 1967-69, is shown in table 2.

The reductions in adult looper catch from 1967 to 1968 and 1969 are clearly evident, with the exception of males at the border. The reduction from the border to the center of the trapped area is also evident when data from a 5-year average are considered.

Table 2.–Summary of light trap collections, 1967-69

Distance from border (ft.)	Cabbage looper moths caught per trap per night					
	Female			Male		
	1967	1968	1969	1967	1968	1969
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
0 (border)	9.16	3.97	5.99	13.95	10.60	13.47
1,000	11.12	3.04	4.37	15.83	6.35	9.32
2,000	12.49	2.44	3.23	15.79	5.86	5.45
3,000	5.62	2.36	2.15	5.97	4.36	5.10
4,000 or center	4.26	2.12	2.35	6.72	4.50	4.16

Figure 39.—Survey trap location with control trap on right and survey trap on left. Pheromone dispensers hang inside cylindrical rain shields above lamps.

Studies conducted on the possibilities of integrated control as an improved means of reducing populations of shade-grown tobacco pests were reported for 1965-1966 by Gentry, Thomas, and Stanley (*1969*) and for 1967, 1968, and 1969 by the same group (unpublished).

Results of the work in 1965 and 1966 indicated that the integrated program was just as effective as the conventional program in the tests. Also, integrated control has the advantage of greatly reducing the number of applications of insecticide each season and eliminates persistent chlorinated-hydrocarbon insecticides from the treatment. In 1967, cabbage looper damage to the tobacco grown under the integrated program was not significantly reduced, but in 1969, damage was reduced by 36 percent. In 1968, no looper damage occurred on either of the treatments. Addition of the synthetic female cabbage looper sex pheromone to the light traps in 1968 and 1969 probably increased the control. About 50 percent fewer applications of insecticide for control of the tobacco budworm and cabbage looper were made on the integrated control program. Thus, insecticide residues were reduced accordingly.

Studies were conducted by Gentry and others (*1970*) in 1968 and 1969 near Quincy, Fla., to determine the effectiveness of traps equipped with BL lamps and baited with the synthetic female sex pheromone for large area control of the cabbage looper on cigar-wrapper tobacco. Involved were 1,200 grower-installed light traps similar to that shown in figure 33, page 61. These had been in use since 1966 in an attempt to suppress the tobacco hornworm and other Lepidoptera attacking tobacco over a 400-square-mile area. After baiting the traps in 1968 and 1969, populations developed later and in smaller numbers than in the previous years. Also, the populations decreased earlier compared with 1967. The number of males caught per trap in the check area traps for both years averaged 4.5 times more than the number caught per trap in the 400-square-mile area. This marked decrease in male population had little effect on mating and fertility in the 400-square-mile trapping area.

European Chafer Survey and Control

The presence of the European chafer in North America was reported by Gambrell and others (*1942*), after damage to turf in Wayne County, N.Y., had been observed and studied during 1940 and 1941. This insect is known to occur in central and western Europe and was first described by Count George von Razoumowsky in 1789.[14] It is believed that a few of these pests entered the United States in the late 1920's or early 1930's.

Following preliminary studies by several workers, Tashiro and Tuttle (*1954*) conducted experiments to develop attractive baits and traps for European chafers in areas of high population. They tested three Japanese beetle traps, a European chafer trap, and a June beetle trap with and without chemical baits. Java citronella oil-eugenol mixture, 3:1 by volume, was tentatively selected as the best bait. They also made tests with traps of different colors in 1950, 1951, and 1953 and found white the least effective and red and black the most attractive. Chinese red was selected tentatively as the best color. Traps with a glossy finish were more effective than those with a dull finish.

European Chafer Attraction to Light and Effects of Trap Design on Beetle Capture

Tashiro and Tuttle (*1959*), interested in a more efficient trap for expanding survey operations, experimented with light traps equipped with a 15-w. BL lamp in 1958. The first traps used were of a modified omnidirectional gravity-type with four baffles, similar to that shown in figure 20, page 31. The BL lamp was found highly attractive to adults of the European chafer. Traps with this lamp captured up to 70 times as many beetles as the most attractive chemically baited traps when exposed to very low populations late in the 1958 season. Light traps caught beetles on nights when none were seen in flight. Chemically baited traps captured beetles only during a 30-minute period at sundown, whereas beetles were captured by light traps throughout a 9-hour

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[14]Mentioned by W. Junk, in Coleopterum Catalogus, vol. 20, part 49, Scarabaeidae 2: 238-241.

night. Contrary to the response of beetles to chemically baited traps, more females than males were caught by light traps.

This discovery of adult European chafer attraction to blacklight led to an intensive research effort to develop a trap for survey operations on this quarantined insect. Various studies were made during 1959-63 to determine the size and type of attractant BL lamp, size, shape, and material for effective trap design, and trap location for insect capture. These studies were conducted by Tashiro, Hartsock, and Rohwer (*1969*) and resulted in the development of the European chafer beetle survey trap, also described by Hollingsworth and others (*1963*). The trap is shown in figure 23, page 38, and its special features are also listed. It was originally designed for a 15-w. fluorescent BL lamp, but a similar unit with a 6-w. lamp has been developed. Either trap operates directly on 110-120 v., a.c. circuit or from 12-volt battery and photoswitch-operated transistorized inverter.

The European chafer beetle survey trap has been in general use in survey operations for several years by the Plant Protection Programs,[15] U.S. Department of Agriculture. Infestations have been detected with this trap at Staten Island, N.Y.; Cleveland, Ohio, and Erie, Pa.

Investigations on the performance of equipment for possible control of the European chafer were conducted by Fiori and Hartsock (unpublished) during 1965-68. Three electrocutor grid traps with BL lamps as lures were evaluated for the percentage of European chafer adults killed by striking the grid. One trap, rated at 5,000 v., 30 ma., killed 37 to 57 percent of the chafers striking the grid, each of the other two killed less than 10 percent. Increased killing power of such traps is a needed improvement.

A 15-w. blue-green lamp, peaking at 500 nm, attracted only 11 percent as many European chafer adults as a 15-w. BL lamp during a 6-night test. Two traps, operated for four nights with a 15-w. BL lamp envelope completely wrapped with black electrical tape so as to emit only infrared radiation, captured one beetle. One trap, operated with a 15-w. BL lamp in the conventional manner under comparable conditions, captured a total of 186 beetles.

Studies were made to determine whether the baiting of the BL survey traps with adult male and female beetles might improve their attractiveness. The results of field tests conducted with virgin or nonvirgin males or females indicated that none of them used as bait improved the attractiveness of the BL lamps, Fiori (unpublished).

Three electric insect traps, all equipped with BL lamps as attractants, were evaluated as control traps against European chafer adults. One suction-type trap was equipped with four 32-w. circline BL lamps, and two gravity-type traps were each equipped with one 15-w. BL lamp. Both gravity traps were similar to the chafer survey trap design, but one insect retainer was of a gallon

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[15] See footnote 7, p. 32.

size while the other was about one quart in size. The suction trap with down draft fan caught from 5 to 21 percent more beetles than the other traps but required almost 15 times more wattage (20 watts vs. 316 watts).

Studies on the efficiency of light traps located at various distances from flight trees (trees to which adult chafers fly at night) were made to provide information on where to place traps in a large area, light-trap control program. When traps were in noncompetitive operation, both Tashiro (*1967*) and Fiori (unpublished) found that BL traps were more efficient if operated under the tree canopy.

The observed tendency for adult chafers to fly to and hover around treetops indicated that chemical traps or BL traps, or both would be more efficient if operated in treetops directly among the beetles. Fiori (unpublished) made tests with chemical and BL traps located near the top of a 28- to 35-foot walnut tree and under the canopy, halfway between the trunk and canopy edge. He found that the trapping efficiency of BL traps operated under the canopy, 5 feet above the ground, was superior to BL traps operated in treetops and far superior to chemical traps operated either under the canopy or in treetops. The efficiency of chemical traps operated under the canopy or in treetops did not improve in the absence of competition from BL traps.

The efficiency of BL traps as control tools was studied by Fiori in 1967 (unpublished). On alternate nights he operated a gravity-type, 4-baffle light trap equipped with a vertically mounted 30-w. BL lamp in 1967 under a 20-foot tall poplar tree. He reported that 1.3 to 3.2 times more beetles were present in and were captured by the operating light trap than were present when the BL trap was not in operation, in four out of five comparisons. The conclusion was based on the assumption that approximately equal numbers of beetles are present in a given tree on consecutive or alternate nights, provided flight conditions are similar. The data also indicated that the operating trap captured 80 to 100 percent of the beetles present.

Southern Potato Wireworm Survey and Control

Slingerland (*1902*) reported that too few Elaters or click beetles were taken in one trap lantern from May 20 to October 1, 1892, to be considered of economic importance. Bogush (*1958*) reported the attraction of 10 species of click beetles (Coleoptera Elateridae) to light traps in Middle Asia between 1930 and 1934. He used a light trap with a 500-w. electric lamp and listed catches of 20,000 to 30,000 Elateridae in a single night (*1936*).

Apple (*1957*) reported that "click beetles were collected in a BL insect trap from May 9 through September 3, 1956, (total 475) with a peak catch of 75 adults during the night of August 5."

Adult southern potato wireworms (*Conoderus falli* Lane) were caught during each month of the year in a light trap equipped with a 15-w. fluorescent BL lamp operated continuously between 1956 and 1967 in one location over sod near Charleston, S.C., according to Day and Reid (*1969*). A survey light trap conforming to Entomological Society of America standards, shown in figure 21, page 34, was used in these studies. The largest numbers were taken between June and September and the smallest between December and March. Catches in this trap during midsummer was highest between 8 and 9 p.m., e.s.t., and 94.6 percent of the total catch occurred before midnight.

In tests for comparing the relative attractiveness of four 15-w. fluorescent lamps, the BL lamps were found more attractive than similar green, daylight, or strontium blue lamps and were used as the standard lamp in subsequent studies.

Light traps equipped with downward suction fans did not increase the catches of the adult insect when compared with the catches of the gravity-type trap without fan. Differences between catches in traps with the lamps positioned at ground level and at 2, 4, 6, 8, 10, and 18 feet above ground level were not significant, but traps at these heights caught more beetles than other traps 50 or 100 feet above ground level. The largest catches were taken over sod and in and at the edges of cultivated fields; the least were taken in woodlands. Moonlight had no apparent effect on catches. In limited tests, averages of 18,728 and 4,357 adults were caught in the light traps during the oviposition season in 1965 and 1966, respectively. Larval populations of fall brood within 100 feet of the traps were not significantly affected.

An experiment on the population suppression of the southern potato wireworm through the use of gravity-type light traps was initiated near Jamestown, S.C., in 1968 and continued in 1969 and in 1970, Day and Crosby (unpublished). A 16-acre field in an isolated area was surrounded by 18 survey light traps (conforming to E.S.A. standards,) each with a 15-w. BL attractant lamp at approximately 200-foot intervals around the edge of the field. The total number of southern potato wireworm adults caught from April 17 through September 30, 1970, was 62,954. The catch at the same location during a similar period was 114,139 beetles in 1968 and 112,195 in 1969. Considerable variation in catches occurred from week to week and among individual traps. There was a low overwintering population in 1968 and moderate populations in 1969 and 1970. This rise in population was not attributed to light traps attracting an influx of adults into the area. Rather, it was attributed to the elimination of wireworm predators by a pesticide that was applied to control soil insects in corn.

The efficiency of the light trap design used above was studied in separate experiments in which water pans plus detergent were used to capture beetles not caught by the light traps. Unpublished data by Onsager and Day show that this light trap was only 19 to 65 percent efficient in catching beetles that were active within 18 feet of the trap.

Striped Cucumber Beetle and the Spotted Cucumber Beetle Survey and Control

Slingerland (*1902*) reported the capture of 101 striped cucumber beetles (*Acalymma vittata* (Fabricius)) and 10 spotted cucumber beetles (*Diabrotica undecipunctata howardi* Barber) in one trap lantern from May 20 to October 1, 1892. The attractant was a kerosene lantern. He listed the striped cucumber beetle as a serious pest with two broods per season.

Taylor and Deay (unpublished) recorded collections, in Indiana, of 219 spotted cucumber beetles and 94 striped cucumber beetles by a unidirectional insect trap with horizontally mounted 15-w. BL lamp, during the period May 17 to August 15, 1951. Six similar traps, equipped with various other lamps, collected a total number of each insect about equal to that of the trap with the BL lamp. During the same year, Girardeau and others (*1952*) collected 17 spotted cucumber beetles in six traps equipped with BL lamps near Tifton, Ga. These two are the first collections of these beetles by BL lamps known to the author.

Barrett, Deay, and Hartsock (*1971*) reported data that had been extracted from experiments conducted during a 15-year period at Lafayette, Ind., on responses of the striped and spotted cucumber beetles to lamp sources of electromagnetic radiation. This work began with Taylor's (*1956*) initial study. In studies of insect attractants, BL fluorescent lamps and green fluorescent lamps, when used alone or in combination, were found to be the most attractive lamps employed as reflected in the trap collections. Two omnidirectional gravity traps of different designs caught significantly more spotted cucumber beetles than a unidirectional trap design; all types were equipped with a 15-w. BL lamp. Small fans with 8-inch diameter blades and 1/100 hp. motor significantly increased the trap catches of both types of beetle. Traps at a 12-foot elevation caught more striped cucumber beetles than at 4 feet.

The degree to which insect damage to vegetables could be reduced through use of electric traps was investigated in central Indiana, from 1958 through 1967, in both small plot and large plantings by Barrett and others (*1971*). In small plot studies, both BL traps and dieldrin application resulted in significant increases in cucumber yields by reducing damage caused by striped and spotted cucumber beetles. In commercial plantings, no significant differences in yields occurred between dieldrin sprayed and unsprayed cucumber plants, nor were there significant yield differences attributable to light trap treatments.

Hickory Shuckworm, Pecan Nut Casebearer, and Pecan Leaf Casebearer Survey and Control

Tedders and Osburn (*1966*) conducted experiments during 1964 at Albany, Ga., to determine whether an insect trap fitted with a BL lamp would attract and trap insects that attack pecans. An omnidirectional, gravity-type trap was used, having four vertical baffles that surround a 15-w. BL lamp and are mounted vertically over a funnel to which is attached a collecting can (fig. 40). They found that three economically important pecan insects, the hickory shuckworm (*Laspeyresia caryana* (Fitch)) the pecan nut casebearer (*Acrobasis nuxvorella* Nuenzig), and the pecan leaf casebearer (*Acrobasis juglandis* (Le Baron)) are highly attracted to BL lamps. This is the first record of such attraction that the author could locate. From the results, Tedders and Osburn decided that BL light trap collections could be useful in timing insecticide applications for insects that attack pecans.

A 3-year study was made by Tedders, Hartsock, and Osburn (*1972*) in an 8-acre pecan orchard to determine whether the hickory shuckworm could be suppressed with a high density of BL traps. Thirty-three survey light traps with 15-w. BL lamps (conforming to E.S.A. standards) were used in the orchard during 1967 and 1968, and the same traps were used with the 4-vaned baffles removed in 1969. The change in the trap design was made to make the trap more specific for shuckworms. The percentage of shuck infestation inside the orchard ranged from 17.6 to 1.2 and from 74.8 to 35.9 outside the orchard. The percentage of shuck infestation within the orchard was 17.2 in 1967, 10.6 in 1968, and 1.2 in 1969. Suppression of the shuckworm with light traps was found to be comparable to suppression with recommended insecticide treatments, under the conditions tested.

Figure 40.—Light traps in Georgia pecan orchard.

OTHER INSECTS ATTRACTED TO ELECTROMAGENETIC RADIATION

Investigations of light attractants used for survey and control of 11 species of economically important insects have been discussed in detail. Several other species and families of insects have been mentioned. A very great many others are attracted to electromagnetic radiation. In discussing which insects are positively photosensitive, Oman (*1961*) stated that "there appears to be no simple, uncomplicated answer to the question of what insects are attracted to induced light. Whether or not an insect exhibits a positive response depends upon various circumstances, some of which concern the insect itself, some of which depend upon the environment, and some that depend upon the nature of the induced light. There are thousands of kinds that respond to light, in varying degrees, under certain favorable circumstances."

The capture of 305 species of Phalaenidae (Noctuidae) order Lepidoptera in light traps equipped with incandescent electric lamps, was reported by Walkden and Whelan (*1942*). Further, they reported that approximately 90 percent of the total catch (525,447) was referable to species of economic importance.

Milne and Milne (*1944*) published a list of insects attracted to incandescent lamps of various colors in their experiments conducted in Virginia during June and July in 1938 and 1940. Lamp colors used were red, orange, yellow, green, blue, purple, and white. They recorded the collection of 660 total species of 11 orders. The orders with numbers of species reported were Lepidoptera 317, Diptera 162, Hymenoptera 71, Coleoptera 42, Homoptera 20, Heteroptera 17, Trichoptera 16, Corrodentia 6, Neuroptera 5, Plecoptera 3, and Mecoptera 1.

Taylor and others in an unpublished report mentioned the survey made of insects of economic importance (in an Indiana market garden area) that were attracted to sources of various wavelength of electromagnetic energy. From this survey, in which they used unidirectional traps equipped with various fluorescent lamps, May 17 to August 15, 1951, Taylor and coworkers found that traps with BL lamps had collected injurious insects of five orders and 85 species. The latter included Lepidoptera 37, Coleoptera 35, Hemiptera 7, Homoptera 4, and Diptera 3. From March 27 to August 25, 1951, at Tifton, Ga., Girardeau and others (*1952*), using the six traps equipped with BL lamps, (mentioned under Hornworms), recorded 332 species of insects from material larger than ¼-inch size. Lepidopterous insects predominated, but species from 12 other orders were identified.

Frost (*1964*) conducted an extensive study on winter insect light-trapping in the same Florida location from November 1 to April 1 during the winters of 1958 to 1960, and from January 1 to April 1 during 1961 to 1963. He used standard Pennsylvania insect light traps (Frost *1957a*) each with one 15-w. BL fluorescent lamp as attractant. He listed 1,610 species of insects taken in light traps and, subsequently, added an additional 385 species (*1966*), making a total of about 2,000 species. Grouped by order and family, these lists comprise the most extensive records of light-attracted insects known to the author.

Of the 20 insects included in the weekly Cooperative Economic Insect Report, detailed investigations have been made on the codling moth, tobacco budworm, corn earworm (bollworm), tomato and tobacco hornworms, European corn borer, and cabbage looper. The other 13 insects listed have been reported or are known to be attracted to BL lamps. They are as follows: Black cutworm *Agrotis ipsilon* (Hufnagel); army cutworm, *Euxoa auxiliaris* (Grote); granulate cutworm, *Feltia subterranea* (Fabricius); variegated cutworm, *Peridroma saucia* (Hübner); armyworm, *Pseudaletia unipuncta* (Haworth); beet armyworm, *Spodoptera exigua* (Hübner); fall armyworm, *Spodoptera frugiperda* (J. E. Smith); yellow-striped armyworm, *Spodoptera ornithogalli* (Guenée); wheathead armyworm, *Faronta diffusa* (Walker); alfalfa webworm, *Loxostege commixtalis* (Walker); beet webworm, *Loxostege sticitalis* (Linnaeus); garden webworm, *Loxostege rantalis* (Guenée); and salt-marsh caterpillar, *Estigmene acrea* (Drury).

Reports of the positive responses of other insects to electromagnetic radiation have been published. A limited number of these papers (key references) are listed by order and subject matter in the Appendix, page 133.

INSECT LIGHT TRAP DESIGN

Insect light trap design involves insect attraction, collection, and retention. The selection of an attractant lamp must be based on the efficiency of the lamp for attracting the one or more species of insects to be trapped. The choice of the collecting device must also be based on its efficiency for collecting and retaining the insect or insects to be trapped. The purpose for which the trap is to be used, survey or control, will determine to a considerable degree the design chosen for retaining insects trapped.

Insect Attraction

Lamp Selection

The extent of attraction of many nocturnal flying insects to BL lamps may vary with individual insect species. For example, the European corn borer moth may be attracted extensively by an incandescent lamp but will respond more strongly to a fluorescent BL lamp of the same wattage as the incandescent lamp.

Killough (*1961*) during 1958 compared the following 16 lamps for their attractiveness to nocturnal insects: 15-w. fluorescent lamps—daylight, white, soft white, standard cool white, cool white deluxe, standard warm white, warm white deluxe (home-line), blue, green, gold, pink, red, blacklight blue BLB, and blacklight BL; 150-w. yellow incandescent lamp; and a 100-w. mercury vapor lamp. The trap used consisted of a lamp suspended above a cylindrical tube, an electric fan in the cylindrical tube, and a collection chamber below the fan. From his comparison, he concluded in part as follows:

"1. Electromagnetic radiation emitted in the near ultraviolet part of the spectrum is the most attractive to insects in general while that emitted in the red and the yellow part of the spectrum is the least. 2. All species of photopositive nocturnal insects are not equally attracted to the same wavelength of electromagnetic energy. 3. The 15-w. BL fluorescent lamp was significantly more attractive to insects in general than any of the other thirteen 15-w. fluorescent lamps, the 100-w. mercury vapor lamp, or the 150-w. yellow incandescent."

Using box-type traps, Belton and Kempster (*1963*) also compared the attractiveness of various lamps for Lepidoptera. From this work, they indicated that attractant light sources can be arranged in the following order of efficiency:

"15-w. fluorescent tubes emitting ultraviolet and visible light > 15-w. fluorescent tubes emitting cool white light ⩾ germicidal tubes behind glass > 15-w. fluorescent tubes emitting ultraviolet but little visible light ⩾ 100-w. mercury vapor bulbs emitting ultraviolet but little visible light."

The similarity of results from this work and that of Killough substantiate further the greater attractance of the BL lamps to many nocturnal insects.

The active response of mosquitoes to lamps radiating visible light led to the use of incandescent lamps in the New Jersey mosquito trap which is used widely as a survey trap for mosquitoes (fig. 11, p. 21). However, Downey (*1962*) reported that two omnidirectional ultraviolet traps each with a 6-w. BL lamp of the design described by Taylor and others (*1956*), captured the mosquito, *Mansonia perturbans* (Walker), as well as the New Jersey trap equipped with a 25-w. incandescent lamp and suction fan. During the same period, three other species of mosquito occurred by the hundreds (267) in the New Jersey traps but did not occur—except for one specimen of *Culiseta morsitans* (Theobald)—in the ultraviolet light trap.

These insect responses have been cited to emphasize the need for information on the reaction of individual species of insects to various wavelengths of radiant energy. While considerable work has been done and is being conducted to determine the response characteristics of particular species, much is yet to be done. In addition, knowledge of the optimum levels for radiant energy output of the attractant lamp or lamps is very limited in scope. More specific information is needed for individual species, not only on lamps but also on traps in which the lamp selected will operate efficiently. Specifically, increasing attractant fluorescent BL lamp capacity from 15 to 30 watts can be made by the addition of a 15-w. lamp to the existing lamp or by replacement with a 30-w. lamp. Increasing the height of the trap to utilize the 30-w. lamp may be less desirable than mounting the two 15-w. lamps in a parallel position, since the length of the lamp could not be increased without increasing the total height of the trap.

Numerous investigations show that virgin females or synthetic sex pheromones, located on or near light traps, increase the collection of males of the codling moth, tobacco hornworm, pink bollworm, and cabbage looper species. The extent to which this type of lure may supplement lamps as attractants in light traps and possibly influence trap design is very dependent on future development of synthetic pheromones.

Insect Collection

Collector Components

The majority of electric insect traps consist of an attractant lamp and a set of baffles mounted vertically above a funnel that guides the attracted insects downward to a collection chamber, usually used as a retaining device.

Funnel.—The first electric light trap with funnel and baffle, known to the author was that reported by McNeill (*1889*)—designed, constructed, and operated in 1888. He used a funnel 6 ½ inches in diameter, with a single tin or glass baffle that stood vertically across the center of the funnel mouth (fig. 2, p. 4). Gillette (*1897*) developed a lantern trap with a funnel 22 inches in diameter at the open end. The inverted truncated cone used by Turner (*1918*), served as a funnel to convey insects attracted to the arc lamp into the trap opening.

The funnel size and slope are important in the design of gravity- and fan-type traps for collecting insects. Previous mention was made of the funnel Hallock (*1932*) added to his Asiatic garden beetle trap in 1928. One funnel used was 4 feet in diameter. From his later work, two traps of similar construction were developed—one with an 18-inch-diameter funnel and the other with a 12-inch funnel, as indicated by Hallock (*1936*). Seamans and Gray (*1934*), Walkden and Whelan (*1942*), and Nagel and Granovsky (*1947*) also used light traps with funnels of various sizes and slopes. The BL Trap Standard for General Insect Surveys, (Harding and others *1966*) recommends a 14-inch funnel with 60° slope. Frost (*1957a*) specified a 12-inch funnel with 60° slope for the Pennsylvania insect light trap.

Stanley and Dominick (*1970*) compared the effects of enlarged funnels and increased lamp wattage on the collection of insects with that of a trap with 18-inch funnel and 15-w. BL lamp commonly used in experiments to control hornworms. They used three experimental gravity-type traps (fig. 41) containing three funnels nested together with diameters of 18, 36, and 60 inches, respectively. Lamp and baffle assemblies were built to permit interchange between traps. BL fluorescent lamps of 15-, 30-, and 40-watt sizes were used in these traps with 60° funnel slope. The experiment was conducted at Chatham, Va., during 4-month summer periods in 1967 and 1968. In all cases the largest number of Lepidoptera, consisting of tobacco and tomato hornworm, corn earworm, and armyworm moths, were collected in the smallest (18-inch) funnel. This was true of some of the collections of Ichneumonidae, very few of which exceeded 50 insects per season. Collections of Coccinellidae were the greatest in the largest (60-inch) funnel, while those of the green stink bug, *Acrosternum hilare* (Say), were more uniformly distributed among the three various sized funnels. More insects were caught

Figure 41.–Experimental gravity-type light trap, with three funnels of 18-, 36-, and 60-inch diameters.

with increased lamp wattage, but the totals were not in direct proportion to the increase in lamp wattage or dimensions.

Hollingsworth and Hartstack (unpublished)[16] also made comparisons of various funnel sizes, including 15-, 30-, 39-, 48-, and 60-inch diameters, on the catch of insects. They concluded that although the 30-inch size is not the best in all cases, it is about the maximum that would be physically practicable for a field trap.

Baffles.–McNeill's (*1889*) previous description of "an insect trap to be used with the electric light" mentioned the use of a single baffle across the mouth of the funnel (fig. 2, p. 4). Williams (*1932*) employed two sets of baffles to lead the insects into his "new type of insect light trap." Hallock (*1932*) reported the construction and testing in 1931 of a baffle-funnel trap "generally called

[16] J. P. Hollingsworth and A. W. Hartstock, Jr. Effect of components on insect light trap performance. Paper presented at ASAE meeting, Chicago, Ill., Dec. 7, 1971.

the baffle trap." The addition of the baffle increased the efficiency of a 4-foot funnel trap. The traps that he reported later (*1936*) with 18-inch and 12-inch diameter funnels to catch the Asiatic garden beetle, were each equipped with a 4-winged baffle mounted above the funnel.

Seamans and Gray (*1934*) also reported using a baffle to prevent the insects from circling the light in a new type of light trap designed to operate at controlled intervals. Nagel and Granovsky (*1947*) described a new turntable light trap that they built and operated in 1934. The collecting assembly of light, baffle, and funnel were very similar to that in Hallock's trap but a hood had been added to keep out rain. This trap, minus the turntable and equipped with one collecting jar, became known as the Minnesota trap, listed by Frost (*1952*).

The traps mentioned above, on which baffles were used, were of the gravity type. Baffles are also used on some suction-type traps, but are not installed in the New Jersey mosquito trap (fig. 11, p. 21). Baffles are not currently used on electric grid traps, although circular grid traps with protruding, electrically charged baffles have been manufactured. Since baffles do substantially increase the catch of most insects, particularly beetles, they are recommended in the standard for BL traps for insect surveys. Some small species, such as leafhoppers, tend to alight on the baffles and do not enter the trap.

Fans.—The development of three electric light traps equipped with fans for survey, control, or both, of specific species or families of insects was mentioned earlier. These insects included the Clear Lake gnat, mosquitoes, and the cigarette beetle. Fan-type traps with electric lamps as attractants are still in general use for survey of mosquitoes and cigarette beetles.

Comparative tests of gravity-type traps, using lamps radiating near-ultraviolet energy, with and without fans have been reported by Glick and others (*1964*), and by Harrell and others (*1967*). Test results showed that use of fans increases insect catches to a limited degree, particularly of Microlepidoptera. Deay and others (*1953*) reported that a cylindrical trap equipped with a fan which forced the insects (several species of flies of the family Sepsidae) into the killing jar was found to be more effective than traps without fans. Sparks and others (*1967*) mentioned a commonly used, gravity-type insect trap that had been modified to incorporate a 10-inch diameter fan with a small motor (fig. 36, p. 65). The fan improves trapping efficiency, particularly of tobacco budworm and corn earworm moths.

Fans do increase electric power requirement and they need regular service for lubrication and cleaning to prevent jamming by deposit of insect material between fan blades and housing. They also tend to damage insects passing through them, creating a problem where identification is desired. Provision must be made in a fan trap to prevent captured insects from escaping when the fan is stopped.

Insect Retention

Insect Retaining Devices

Insect retainers are essential for survey light traps to permit identification of insects attracted and collected. Retainers (collection chambers) are also necessary on traps of the gravity and suction types used for insect control. They may not be necessary where the insects are killed, as by a grid-type trap, and where dead insect accumulation beneath the traps is not objectionable. Rodents, birds, and other scavengers usually frequent such installations outdoors and dispose of dead insects. However, retainers are required on all indoor light trap installations.

Retaining devices are made in various designs and degrees of efficiency. Probably one of the first such devices was the shallow pan—partly filled with water with a kerosene film—suspended a few inches below the lamp as shown in figure 13, page 23. The ordinary washtub instead of the smaller pan was used for increased insect catches (fig. 42). More recently, a 55-gallon, steel barrel, with one end removed and filled with water and diesel fuel, has been adapted to retain insects and is mounted beneath the trap (fig. 39). A very simple trap with a BL lamp mounted over a 34-inch-diameter, 6-inch-deep plastic dish is also of recent development, Sparks and others (*1967*).

Insect retainers that can be attached directly to a light trap have been made of various materials—cloth, polyethylene (Powers *1969*), screen wire, metal, and glass. Cloth bags have proved very unsatisfactory because the material rots early or is damaged from the outside by rodents or by certain beetles inside (fig. 43). Retainer baskets of heavy screen wire or hardware cloth are used successfully where it is desired that small insects be allowed to escape. However, if the baskets are not emptied regularly, they may deteriorate rapidly, which reduces their usefulness (fig. 44). A galvanized steel collection container (fig. 21, p. 34) is the type of metal retainer recommended in the BL Trap Standards for General Insect Surveys. An emptying drain is necessary where such retainers are installed on traps without covers. For many years, glass jars have been used as retainers on survey traps. The glass jar varies in size from one pint to a half-gallon and is usually provided with a screw top for joining with the screw-type cap attached to the bottom of the trap funnel.

The desirability and need of a method, other than manual, for changing insect retainers at frequent and regular intervals stimulated the development of light-trap designs that would make the changes automatically. One of the first designs, developed by Seamans and Gray (*1934*), was a multiple unit consisting of seven traps. Each of these traps operated for a preset period, usually 1 hour, was then turned off by a clock, and the next one set in operation.

Williams (*1935*) added a retainer bottle-changing mechanism to the trap he had developed in 1923, previously mentioned. Eight killing bottles stood in shallow grooves on a turntable that was actuated by a clockwork device to place each bottle under the trap funnel once during the night. Various changes

Figure 42.–Electric insect trap used for Cyclocephela in 1939. A common metal washtub, partly filled with water, served as the insect retainer.

and improvements in the turntable trap separation device developed by Williams were reported by Hutchins (*1940*), Horsfall and Tuller (*1942*), Nagel and Granovsky (*1947*), Frost (*1952*), and Standfast (*1965*).

A second type of separation device, called the disk or falling disk type, was first reported by Johnson (*1950*). He designed a trap in which the catch is deposited in a collecting tube into which closely fitting disks fall, one every hour, thus segregating the catch into successive hourly samples. Taylor (*1951*), Harcourt and Cass (*1958*), and Horsfall (*1962*) also reported on traps they had built with falling disk-type separation devices. All of these were suction-type traps, whereas the turntable-type traps (excepting Standfast) were gravity type.

An automatic device for dividing and packaging light trap insect catches according to time intervals, of as little as 5 minutes, has been developed by

Figure 43.–Trap with a cloth bag for retaining insects.

Hartstack and Hollingsworth (*1968*). Insects collected in the gravity-type trap move from the killing chamber into a paddle wheel compartment which deposits them between sheets of rolled plastic film where they are retained until the package is opened for identification (fig. 45). A prototype unit, in use for 3 years, has had no mechanical failures and required only minor adjustments.

Killing Agents Used in Insect Retainers

A killing agent in the insect retainers prevents insects from escaping, being damaged by other insects, or both. Currently, the use of killing agents in survey light traps is a common practice. More than a century ago, this practice was used in an insect retainer of fairly tight construction. In Glover's new American moth trap (fig. 1, p. 3), a large drawer was used as the insect container and was fitted with a smaller drawer which contained chloroform for immobilizing the captured insects (Knaggs, *1866*).

McNeill's (*1889*) insect trap to be used with the electric light provided a killing agent in the bottom of the insect retainer. He first put in a layer of potassium cyanide crystals, then over this a half-inch layer of plaster of Paris (fig. 2, p. 4). Gillette (*1897*) also utilized potassium cyanide as a killing agent at the bottom of the insect retainer of his lantern trap. He filled the top of the insect container with excelsior to prevent injury to the captured moths.

Frost (*1964b*) summarized his studies on killing agents and containers for use with insect light traps. He reported that pint mason jars with sodium or potassium cyanide, prepared in the usual manner with a layer of plaster of

Figure 44.—A metal insect retainer basket; must be emptied regularly to prevent excessive rusting.

Paris, were most satisfactory. Calcium cyanide, placed in a small container and covered with a piece of loosely woven muslin, gave the quickest kill and yielded the best specimens but was somewhat inconvenient because it had to be replenished each night.

Field tests were conducted by G. G. Rohwer and S. A. Rohwer (1964) in New Jersey during 1962 in an attempt to improve the effectiveness of killing agents used in BL survey traps. The tests were initiated to find a satisfactory chemical for use in killing trapped insects. Calcium cyanide, the most

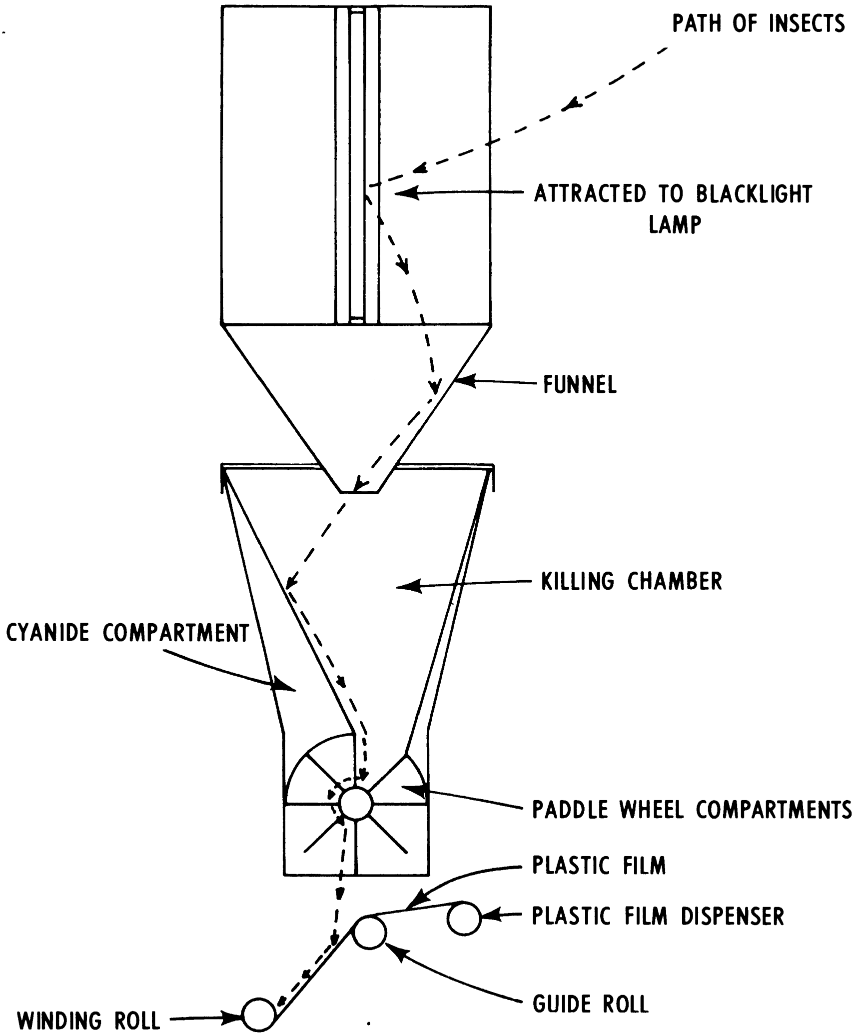

Figure 45.–Sectional view of automatic device for dividing and packaging light trap insect catches according to time intervals.

universally employed material, is highly toxic and the insects are stiff, so often in poor condition for identification. The Rohwers initially utilized traps that were typical of those used by various workers for making general insect surveys and which had drain openings in their collection containers. Subsequent results, however, indicated the need for a modification of the collection container to reduce air circulation which dissipated the fumigants. Twelve chemicals or chemical combinations were tested involving 40 varying chemical concentrations or combinations and methods by which the fumigants were dispensed. Of the chemicals tested, ethyl acetate appeared to be the most promising.

White (*1964*) developed "a design for the effective killing of insects caught in light traps." The design embodies a removable collecting chamber with a centrally mounted compartment for storing the killing agent (potassium cyanide) and for supporting a funnel to dispose of rainwater. The lid is soldered to the cone of the light trap. The compartment holds a large amount of the killing agent, so frequent refilling is unnecessary if the agent is chemically stable.

Preferences for killing agents differ widely among entomologists. Safety in using these chemicals is an important consideration in many trapping locations. The use to be made of the collected insects—mounting requirements particularly—affects the characteristics required of the agent. The characteristics of the agent (whether solid, liquid, or gas), volatility, flammability, vapor density, and so forth affect the design requirements for the insect retainer.

Little documented comparative research on performance of killing agents exists beyond that mentioned. While relatively poor performance was ascribed to dichlorvos concentrate by Rohwer and Rohwer (*1964*), numerous users of light traps have recently been well satisifed by the performance of resin strips impregnated with this material.

Horsfall (*1962*) used heat from a 192-w. electric heating tape to kill the insects collected in his trap for separating collections of insects by interval. Hardwick (*1968*) also reported using heat from a 100-w. heating element in his trap to vaporize the killing agent (tetrachloroethane) and to warm the reception chamber so that the chemical would remain vaporized.

Heat alone is satisfactory as a killing agent but requires considerable energy input, and temperature control to prevent damage to insects is difficult in outdoor situations.

Costs of Trap Construction and Operations

Both initial and operating costs must be considered in insect trap design. These cost factors involve considerations beyond mere trap performance. They include durability, ease of fabrication, safety, investment to provide electric supply, ease of servicing the trap, and potential vandalism. As in other economic situations, compromise decisions must be made: High costs for electric distribution may necessitate a minimum number of locations with maximized catch per location. Long-term trapping plans or choice of corrosive killing agents used may justify the use of costly and more durable materials. Minor compromises on sizes, shapes, and fastenings may greatly simplify assembly work, permit more efficient cutting of stock materials, or permit larger quantity procurement to reduce initial costs. Conversely, additional expense in fabrication to assure interchangeability of parts, simplify servicing, or reduce pilferage may significantly reduce operating expenses. Safety of both operating personnel and the curious public is essential. Costs of design, installation, and servicing to achieve this and to meet Underwriters' Laboratories standards must be recognized as imperative.

Decisions concerning choices of components which affect trap performance also "lock-in" associated cost situations. Use of a fan involves cost for a motor, significant energy consumption for operation, and servicing requirements for motor maintenance and for removal of accumulated debris.

The kind and size of lamp used in a light trap may affect operating cost as well as initial cost. Incandescent lamps are lower in first cost than ultraviolet lamps but are not used as much because they are considerably less attractive to most night-flying insects. Incandescent lamps are used mainly in mosquito survey traps. Straight-tube fluorescent BL lamps attract more insects per watt of input energy than do the circline BL lamps. Circlines also cost much more and are vulnerable to weather damage because of the close spacing of the pins in their connectors across which voltage is applied. Thus, on a wattage input basis the straight-tube BL lamp has a lower initial and operating cost than the circline BL lamp for attracting many night-flying insects.

Detailed technical observations and studies of large-scale light-trap operations that have been made during the past decade are providing new information on light trap performance requirements. These findings may be reflected in lower overall costs by design changes, as shown by the following examples: Frequent motor burnouts in one suction-type trap were overcome by increasing motor size and by redesigning the fan. Poor performance because of power leakage in a grid-type trap was remedied by the use of higher quality insulators. Shorting from a porcelain lamp socket in a gravity-type trap was eliminated by installation of waterproof lamp sockets. Plastic fluorescent lampholders have been replaced by weatherproof neoprene units.

Additional pertinent observations on desirable light trap characteristics and trap installations have produced the following recommendations:

Use traps that carry the approval seal of Underwriters' Laboratories for safety from electrical shock and to meet local electrical inspection requirements. Such approval should cover the entire trap unit, not merely the individual components.

Select traps of good fabrication and materials to withstand the effects of wind and general weather.

Install safe, adequate electric service for operating the traps. Field wiring for distribution systems should include a physical ground lead (3-wire grounding plug) and must also be carefully installed in accordance with the provisions of the National Electric Code[17] insofar as is possible.

Provide a post, tripod, or other supporting device of adequate strength and stability to minimize damage of overturning or swaying in the wind.

Following the installation of light traps, a maintenance program must be planned by the operator and carried out by him, the trap manufacturer's representative, or possibly by the power supplier. This need for maintenance was very evident from a 3-year study of a group of 300 farmer-owned traps in Horry County, S.C., conducted by the South Carolina Agricultural Experiment Station and U.S. Department of Agriculture during 1964-66. The primary purpose was to determine the effectiveness of electric light traps and their design for the control of hornworms and other tobacco insects by using a density of three traps per square mile in a 20-mile-diameter circular area.

The lack of any planned maintenance program forced the investigators to help with trap repair and maintenance to insure that the traps were in operating condition during 1964 and 1965 (Hays, *1968*). During early 1966, an inspection and maintenance program by project agricultural engineers disclosed that replacements were needed for 82 percent of the lamps, 7 percent of the lamp starters, 9 percent of the ballasts, and 20 percent of the collection baskets. Also 7 percent of the traps needed other repairs. Such replacements and repairs are a part of the operating cost, but they must be provided to insure effective trap operation.

CONCLUSIONS AND RECOMMENDATIONS

General Conclusions

1. The near ultraviolet region, 320 nm-380 nm, of the electromagnetic spectrum has been found to be the most attractive radiant energy to a great many nocturnal insects.

2. Radiant energy in the visible portion of the electromagnetic spectrum, 380 nm-760 nm, is attractive to many nocturnal insects. The blue and green sections of the visible area are decidedly more attractive than are the yellow and red sections.

3. Some insects have shown peak responses to radiant energy in both the near ultraviolet and visible regions of the electromagnetic spectrum, but these responses varied with the energy levels of the source.

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[17]National Fire Protection Association, 60 Batterymarch Street, Boston, Mass. 02110.

4. Radiant energy of a specific wavelength does not attract all species of phototactic nocturnal insects equally well.

5. An increase in lamp wattage output of a given wavelength increases the attraction of insects when all other factors are equal. The increase in attraction is usually less than the proportional increase in lamp wattage.

6. Male insects of certain species are attracted to light traps in greater numbers when the traps are baited with virgin females or a sex pheromone of the same species than by the lamp attractant alone.

7. Positioning of the lamp in a light trap so as to provide maximum exposure to insects and also to partly lead them into the trap is advisable.

8. Baffles tend to prevent insects from circling a light trap and to increase the catches of large moths and beetles by the trap.

9. A suction fan installed in a light trap will increase the catch of small insects, particularly Microlepidoptera and mosquitoes. A fan increases electric power requirement and requires regular service to insure satisfactory operation.

10. Traps should be made of durable materials, well fabricated, and properly installed or they will not withstand wind and weather damage.

11. Approval of the entire light trap—not merely the electrical components—by the Underwriters' Laboratories is desirable to insure safety to operators and others who may be near such equipment.

12. Standards have been developed for blacklight traps that are used in general insect survey programs to determine the time of occurrence and abundance of established insect pest species, such as the corn earworm, fall armyworm, European corn borer, cabbage looper, and others.

13. Specialized survey traps have been developed for use in surveys of certain insect groups, such as mosquitoes, or of individual species, such as the European chafer.

14. Environmental factors affect light trap catches of insects. Some species will not fly at temperatures below a given level, others will not fly when winds exceed a certain velocity. Results of tests indicate that light traps that are shielded from the prevailing winds are more efficient in collecting insects than traps in more exposed locations.

15. Instances have been recorded of major reductions in outdoor infestation of European corn borer, codling moth, and tobacco hornworm in small areas by use of light traps. However, large area coverage is essential for insect suppression unless true isolation of an area is possible.

16. Light traps offer promise of suppressing insect populations when the traps are used alone or in an integrated control program planned to reduce the required number of pesticide applications or to provide more effective control measures. The most promising results with light traps were obtained with hornworms in tobacco and with certain pecan insects.

Problems To Be Solved in Electric Insect Trap Research

Influence of Meteorological Variables on Light-Trap Collections

A major need exists for research with the objective of using light-trap insect collections as a tool for predicting insect population behavior. This will involve establishing a clearer understanding of the influence of meteorological variables on insect-population behavior and translating the effects of meteorological variables on light-trap catches to reflect true population behavior.

A multitude of meteorological elements are involved in complex and interdependent relations, compounded by the multiple factors affecting insect behavior. Williams (*1951*) and King and Hind (*1960*) thought in these terms and attempted to establish relationships between weather factors and light trap insect collections. Their efforts, while fruitful, were seemingly limited by the complex relationships encountered.

A similarity and relation to the problems of weather forecasting are apparent for predicting insect population behavior. Computer analysis of the myriad of variables offers the most promising approach. The establishment of Weather Service Offices for Agriculture[18] is a step in this direction. Once reliable relations among weather factors are established, perhaps relationships between weather changes and insect behavior can follow.

Physiology of Male Insect Response to Radiant Energy and Sex Attractant

Further research is needed to gain information that will provide a fuller understanding of the physiological background for the sensitivity of many insects to near ultraviolet radiation. A solution to this question might be expected to explain differences in various insect responses to ultraviolet lamps when operated in light traps under comparable conditions.

A related problem concerns the relative responses of male insects to ultraviolet radiation and to sex pheromones. Fabre (Teale *1961* and Rau and Rau *1929*) observed that the attraction of virgin females to males of the same species was superseded by the attraction of light as the males approached the females. Henneberry and others (*1967a*) found that when traps with BL lamps were baited with caged, virgin female, cabbage looper moths, increased numbers of male cabbage looper moths were caught as compared with numbers

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[18]National Oceanic and Atmospheric Administration, U.S. Dept. Commerce, Washington, D.C.

in similar unbaited traps. Virgin females, placed as far as 40 feet from the light trap, increased the numbers of male moths caught. Much more information is needed on the relative physiological response of male insects to these two attractants.

Improvement of Light Trap Design

Another problem needing additional research is that of determining the optimum type of light trap and the density of trap installations required for possible control of economic insects that are light attracted. For example, installations of three gravity-type traps per square mile in North Carolina and St. Croix, have suppressed the tobacco and tomato hornworm populations rather well, partly because of the flight range of the moths. A suction fan added to the trap did not increase the catch of hornworm moths nor did a twofold or fourfold increase in wattage (15 to 30 or 60) of the BL attractant lamp, in tests conducted by Stanley and Smith (unpublished). However, as previously reported, Hoffman and others (*1966*) found that for each additional virgin tobacco hornworm female (up to 10) placed with the light trap, the male catch increased by a factor equal to the male catch of the trap without virgin females.

Possibilities of improving light trap design for more effective capture of another insect, the hickory shuckworm, were indicated by Tedders and others (*1972*), after a 3-year study. They commented that suppression of the shuckworm with light traps was found to be comparable to suppression with recommended insecticide treatments under the conditions tested. Their results were achieved with off-the-shelf traps which were basically designed for insect survey use. They also indicated that "If, through research, a control trap which requires less servicing, which is more specific for pecan pests and is less expensive, can be devised, then BL traps should have a place in pecan culture."

Light Trap Installation Density

Wolf and others (*1971*) have proposed a method for determining the installation density of light traps required to reduce the native population of a certain insect by a given amount. Under field conditions, the characteristics of a single trap are measured and an empirical trap-density function is determined. This trap-density function accounts for changes in trap performance when operated with overlapping trapping patterns at various trap densities, and, in some instances, may be used for other traps having similarly shaped trapping patterns. Research in establishing the density of traps involves the measurement of trap characteristics by releasing laboratory reared and marked specimens. It is assumed that such specimens, released in the field, react to a trap in a manner similar to that of native insects.

Hartstack and others (unpublished) used the method suggested by Wolf and others (*1971*) in field tests in Texas in 1967 with a very limited number of insects. They continued their work on larger scales in 1968 and 1969. In a 4-month period (June-Sept. 1969), they marked and released more than 9,000 native moths (bollworms and cabbage loopers). Calculations, based in part on actual results, indicate that the use of light traps can reduce substantially the adult populations of these two species. However, the trap installation density required for effective control would probably be much greater than that used in most previous experiments. Confirmation of these conclusions will require actual field control experiments. Also, trap spacings for use with other economic insects need to be determined.

Sexual Condition of Female Moths in Light Trap Collections

Greater information on the sexual condition of female insects at the time of their capture by light traps is needed to account for differences in hourly and seasonal collections of males and females of a given species. Stewart and others (*1967*) found from hourly sampling of tobacco hornworm moth catches in BL traps that both sexes were captured all night, with many more males than females being taken at all hours. A relatively low number of males were taken between 8 and 9 p.m., but during the next hour, the maximum male capture of the night occurred. The authors comment that "perhaps our sharp increase in catch of males compared with females between 8 and 10 p.m. resulted from the movement of males in quest of females."

Wolf and others (*1969*) reported the number of corn earworm moths caught in 36 BL survey traps at Red Rock, Ariz., in 1967. Detailed examination of the records shows that, during the period May 22 to July 25, more females than males were captured, although for the season the average male catch per trap was more than twice that of the female catch. A similar situation occurred at Florence, S.C., in 1969 where the ratio of the bollworm moth catch for the season was 1.48 male to 1 female, yet during the first half of a 4-month season the female catch exceeded the male catch by the same ratio. Geier (*1960*) found that à light trap (with mercury vapor lamp) drew samples of quite significantly younger female codling moths from the population than did bait pans. Much remains to be learned about the optimum time of attraction of other female insects to electromagnetic radiation sources.

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